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SOCIOECONOMIC ANALYSIS OF HAZARDOUS WASTE MANAGEMENT ALTERNATIVES: METHODOLOGY AND DEMONSTRATION

by

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16. ABSTRACT

A methodology for analyzing economic and social effects of alternatives in hazardous waste management is presented and demonstrated. The approach includes the use of environmental threat scenarios and evaluation of effects on and responses by parties-at-interest. The methodology is demonstrated by a case study of alternative approaches to hazardous waste management for Oregon.

The report organizes, summarizes, and provides extensive information on hazardous waste management techniques. Research on risk preferences and its relationship to decision-making is reviewed, and appendices on methods for valuing various effects (such as environmental impacts), public attitudes toward environmental issues, and intergenerational discounting are included. The report constitutes a useful manual for hazardous waste management personnel and policymakers involved in environmental quality management.

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of the environment and the interplay between its components require a concentrated and integrated attack on the problem.

Research and development is the first necessary step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and the solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health and aesthetic effects of pollution. This publication is one of the products of that research and provides a vital communications link between the researcher and the user community.

The report describes and demonstrates a methodology for the analysis of the complex socioeconomic problems associated with hazardous waste management. It should be of wide value to both researchers and decisionmakers who are concerned with hazardous wastes.

Francis T. Mayo, DIRECTOR
Municipal Environmental Research
Laboratory

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ABSTRACT

This report develops and presents a methodology for analyzing the economic and social effects of alternative approaches to hazardous waste management. The techniques of economic analysis that have been developed for conventional pollutants are not always appropriate or feasible for hazardous wastes, and thus a new approach is desirable. The approach proposed involves (1) the generation of a series of environmental threat scenarios that might arise from the use of various hazardous waste management techniques, and (2) identification of parties-at-interest to these techniques. By examining how the parties-at-interest are affected by alternative approaches to hazardous waste management, it is possible to make decisions based on economics that recognize sociological factors.

This approach is applied in a generalized manner to the various techniques that can be used to manage hazardous wastes, and the methodology is demonstrated in two management decision situations. One example analyzes alternative techniques that could be applied to a single waste stream, the second is a case study of alternative approaches to hazardous waste management for Oregon. These cases demonstrate that though the methodology simplifies the decisionmaker's task, the ultimate decision depends on the degree of risk aversion favored and may involve subjective elements.

The report organizes, summarizes, and provides references to extensive data on various hazardous waste management techniques and their associated risks. It includes appendices on the methods that may be used to value the various effects (such as environmental impacts) of waste management techniques, on public attitudes toward environmental issues and on methods of handling effects that extend over a long period of time. This includes a pragmatic solution to the problem of intergenerational discounting. Research on risk-taking and its relationship to decisionmaking is also reviewed. The report should constitute a useful handbook for hazardous waste management personnel and for many others who are involved in environmental decisionmaking.

This work was supported in part by Grant No. R804661 awarded by the U.S. Environmental Protection Agency to the Colorado School of Mines, Golden, Colorado. This report was submitted in fulfillment of this grant which extended from November 1976 to April 1979. Work was completed as of September 1979.

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EPA-287 (Cin.)
(4-76)

CONTENTS

Foreword iii
Abstract iv
Figures. viii
Tables ix
Acknowledgements xi

Section 1. Introduction 1

- Research Objectives 1
- Scope 2
- Organization of the Report. 3

Section 2. Conclusions and Recommendations. 4

- Summary of Findings 4
- Applications of the Methodology 6
- Recommendations for Further Research. 6

Section 3. Overview of Hazardous Waste Management 8

- Unique Aspects of Hazardous Waste Management. 8
- The Nature of Hazardous Wastes. 10
- Techniques for the Management of Hazardous Wastes 18
- Legislative Background of Hazardous Waste Regulation in the United States. 18
- Previous Research on Hazardous Waste Management 22

Section 4. Economic and Social Aspects of Hazardous Waste Management 27

- Cost-Benefit and Risk-Benefit Analysis for Environmental Problems. 27
- Threats That May Arise From Hazardous Wastes. 31
- Economic and Social Effects of Hazardous Waste Management Techniques 33
- The Parties-at-interest in Hazardous Waste Management 38
- The Socioeconomic Interaction Process 43

Section 5. General Methodology for Analysis of Hazardous Waste Management Alternatives. 52

Introduction. 52
Theoretical Considerations. 53
Use of Threat Scenarios 58
Prerequisite Information for Analysis 61
The Analytical Framework. 67
Aids to Decisionmaking. 74

Section 6. Application of the Methodology to a Single Waste Stream. 78

Introduction. 78
The Problem 78
Threat Scenarios. 79
Analysis of the Alternatives. 80
Decisionmaking. 82

Section 7. Case Study of Hazardous Waste Management in Oregon 86

Introduction. 86
Prerequisite Information and Decisions. 90
Application of Analytical Framework 98
Decisionmaking. 121
Appendix:Development of Certain Threat Scenarios. 128

References 134

Appendix A. Hazardous Waste Management Techniques 148

Techniques Involving Waste Stream Changes 148
Resource Recovery 149
Waste Treatment 149
Storage and Disposal Techniques 152
References. 159

Appendix B. Environmental Threats Associated with Hazardous Waste Management Techniques 164

The Nature of Hazardous Waste Threats 164
Probabilities That Threats Will Occur 179
References. 185

Appendix C. Valuation of the Effects of Hazardous Waste Management Techniques 190

Control Costs 190
Valuation of Environmental Impacts. 194
References. 208

Appendix D. Public Attitudes Toward Environmental Issues. 214

Introduction. 214
Public Concern for the Environment. 215
Attitudes and Behavior of Specified Parties 222
The Economics of Pollution Abatement. 230
References. 233

Appendix E. Factors Influencing Discount Rates for Environmental Projects. 240

Introduction. 240
The Social Discount Rate. 240
Adjustment of the Discount Rate for Risk. 241
Intergenerational Effects 242
Objections to Discounting 243
Application to Hazardous Waste Management 244
References. 247

Appendix F. Risk and Decisionmaking 249

Aspects of Risk 249
Decisionmaking Under Uncertainty, and Risk Aversion 251
Risk and Society. 253
References. 258

FIGURES

Number		Page
1	Routes by which hazardous wastes can affect the environment .	11
2	The Battelle hazardous waste decision model	15
3	Conventional economic approach to pollution control	29
4	Morphological map of environmental threats.	34
5	Interaction model for hazardous waste management.	44
6	Model for pollution toleration.	50
7	Process for assessing damages associated with hazardous waste management.	59
8	The geography of Oregon	87
9	Approaches for hazardous waste management in Oregon	99
B-1	Process for estimating damages caused by spills (sulfuric acid) into water.	169
B-2	Contamination of groundwater by waste disposal practices. . .	175
B-3	Frequency of property damage resulting from natural and man-caused events	181
B-4	Frequency of fatalities due to man-caused events.	182
B-5	Frequency of fatalities due to natural events	182
F-1	Utility of wealth for a risk-averse individual.	251
F-2	Determinants of acceptable risks as indicated by revealed and expressed preferences.	257

TABLES

Number Page

1 Hazardous Materials Classification Criteria 13

2 Techniques for the Management of Hazardous Wastes 19

3 Potentially Hazardous Wastes Generated in the United States . 24

4 Environmental Threats in Hazardous Waste Management 32

5 Major Threats That May Occur in Hazardous Waste Management. . 35

6 Environmental Threats, Costs, and Parties-at-interest for Hazardous Waste Management Techniques 41

7 Matrix of Effects on the Parties-at-interest. 71

8 Summary of the Methodology. 77

9 Analysis of Five Alternative Waste Disposal Plans 81

10 Comparison of Three Selected Waste Disposal Plans 83

11 Employment by Industry in Oregon and the United States. . . . 88

12 Generation and Disposal of Potentially Hazardous Wastes in Oregon 91

13 Oregon Firms That May Generate Hazardous Wastes 94

14 Projected Data on Future Hazardous Waste Generation in Oregon Under the Status-quo Approach. 101

15 Threats Associated With Three Approaches to Hazardous Waste Management. 108

16 Descriptions of Principal Threats 109

17 Summary of Approaches 111

18 Generator's Costs for Alternative Approaches. 112

19 Impacts of Different Hazardous Waste Management Approaches on the Parties-at-interest 115

20 Comparison of Five Hazardous Waste Management Approaches. . . 119

21 Comparison of Two Hazardous Waste Management Approaches . . . 126

22 Theoretical Average Concentrations of Ions From Heavy Metals Wastes at Portland, and Relevant Standards . . 129

A-1 Currently Available Hazardous Waste Treatment and Disposal Processes. 150

B-1 Selected Transport Accident Statistics. 166

B-2 Summary of Pollution-caused Fish Kills for the United Sates, 1960-1975. 170

B-3 Extent of Fish Kill Damage. 171

B-4 Analysis of 1970 Fish Kill Data 171

B-5 Mechanisms Involved in Damage Incidents by Disposal Method. . 173

B-6 Summary of Data on 42 Municipal and 18 Industrial Landfill Contamination Cases. 177

B-7 Sample Components of Release Sequence Probabilities for Geologic Disposal 184

C-1 Estimated Cots of Some Disposal Techniques. 191

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Members of the staff of both the Office of Research Services, Colorado School of Mines, and the Industrial Economics Division, University of Denver Research Institute, provided valuable support services. Ms. Nanci Avitable functioned efficiently and cheerfully as my research assistant and coauthored Appendix D, and Ms. Jeanne Vannoy helped edit the final report.

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SECTION 1

INTRODUCTION

For years, the Love Canal in upstate New York had been used as a dumping ground for chemical wastes. This had been done legally, according to the practices of the 1940's and 1950's. Recently, serious pollution problems became apparent when trees died, pools of bubbling liquids appeared in low-lying backyards, and fumes permeated basements. Evidence of miscarriages and birth defects was reported, the State Health Commissioner urged immediate evacuation of pregnant women and young children, and homes in the area became virtually unsaleable (Anon., 1978a). The problem attracted international attention when it became the subject of an article in The Economist after President Carter declared the Love Canal a disaster area in August 1978 (Anon., 1978c).

The incident described above is not an isolated one. Although estimates vary widely, one authoritative source (Anon., 1978a) reports that more than 1,000 disposal sites comparable to the Love Canal may exist in the United States. The management of hazardous wastes has been of growing concern to environmental agencies for some time. In December 1977, the Council on Environmental Quality stated:

> The problem of hazardous waste has grown to serious proportions in recent years for several reasons: as a nation, we are increasing our consumption of all materials, including hazardous materials; several toxic substances have been banned from use, and existing stocks are "thrown away"; and as air and water pollution controls increase, hazardous waste residues result.
> (Council on Environmental Quality, 1977:45)

Incidents such as that of the Love Canal and the Keypone tragedy at Hopewell, Virginia, in 1976 (Council on Environmental Quality, 1977) are, however, likely to intensify the pressure for public involvement in environmental management decisions, and for careful consideration of public attitudes in these decisions. Indeed, when discussing the nuclear power issue, a recent engineering journal editorial stated that "The need to pay constant attention to public attitudes may well become a feature of all engineers' lives." (Anon., 1978b:333)

RESEARCH OBJECTIVES

The objective of the research was to develop and demonstrate a methodology for the analysis of hazardous waste management problems that is

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based on economics but is cognizant of sociological factors. The methodology was expected to take the form of an analytical framework that could be adapted by decisionmakers to suit a particular problem or situation. The research was expected to throw some light on the attitudes of the public and special interest groups toward hazardous waste management alternatives, and toward taking environmental risks. It was also expected to provide some generalized analysis of the costs and risks associated with the various techniques (i.e., technical options) for hazardous waste management.

This report is timely because it provides environmental decisionmakers with a methodology for the analysis of hazardous waste problems that can respond to societal concerns and reflect public attitudes. The methodology is designed to permit the identification of costs and other effects associated with alternative approaches to hazardous waste management. It encourages a decisionmaker to consider attitudes and equity as he assesses trade-offs among alternatives. As exemplified by incidents such as the Love Canal disaster, the effects that may arise from some hazardous waste disposal practices are often ill-defined or virtually unknown. The methodology encourages a decisionmaker to identify possible environmental threats and to evaluate the costs of different degrees of risk aversion.

SCOPE

This report deals only with wastes and their management. It does not address the broader question of curtailing the economic activity that generates such waste. The research was oriented toward industrial process wastes as opposed to special wastes such as hospital wastes, pesticide containers, U.S. Department of Defense wastes, sewage sludge, and mine tailings. (The latter two wastes are not normally considered hazardous.) The research specifically excludes radioactive wastes, although research on radioactive waste disposal was reviewed for its applicability to nonradioactive wastes. Note, however, that the evaluation methodology could be applied to any category of waste.

The methodology is intended to be used to evaluate alternative approaches to hazardous waste management on a local or regional basis, but it could also be used to evaluate specific problems on a national basis (e.g., the disposal of polychlorinated biphenyls [PCB's]). The role of the methodology is that of an aid to decisionmaking and value judgments are required to choose between alternatives.

The potential utility of this report goes far beyond the applications mentioned above. The methodology itself could be adapted to decisionmaking for a wide range of environmental problems. The compilations of data in Appendices A and B should be useful to those concerned with the management of hazardous wastes at many levels, and Appendices C through F should be of value to a variety of persons concerned with environmental issues.

One important caveat is in order. Much of the work described herein, and especially that relating to the case study in Section 7, was performed in 1977. Since then the U.S. Environmental Protection Agency (EPA) has developed hazardous waste regulations under the 1976 Resource Conservation

EPA-287 (Cin.)
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and Recovery Act (RCRA). Some of the details in this report do not reflect the impact of these regulations, and some of the waste management techniques discussed may not be permissible under the new law. However, the scope of this study is not restricted to situations or substances regulated under the RCRA. It is intended to assist hazardous waste management decisionmaking under a variety of circumstances, including those that might not be covered by regulations (e.g., wastes that are not defined as hazardous under present Federal regulations). The methodology could also be applied to evaluating possible alternatives to existing regulations.

ORGANIZATION OF THE REPORT

The report has two main aspects. First, Sections 1 through 5 analyze the special features of hazardous waste management, describe the decisionmaking methodology and discuss applications. Second, Sections 6 and 7 demonstrate the methodology in two different situations. Appendix A describes hazardous waste management techniques, and Appendix B discusses the environmental threats that may be associated with those techniques. Appendix C describes the methods that may be used to value environmental effects, and Appendix D reviews surveys of attitudes towards the environment. Appendix E discusses the discounting of environmental effects, and Appendix F presents material on the role of risk in decisionmaking.

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SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

SUMMARY OF FINDINGS

The management of hazardous wastes has certain features that from the economist's viewpoint differentiate it from that of other wastes or pollutants. A basic characteristic of a hazardous waste is that it poses far stronger threats to man or the environment than a nonhazardous waste. Because of the strength of these threats, waste management techniques that may be acceptable for nonhazardous wastes, such as using the assimilative properties of the environment, are not suitable for hazardous wastes, and techniques that are intended to minimize the exposure of these wastes to the environment must generally be used. Consequently, when analyzing potential damages from hazardous wastes, the economist or decisionmaker is largely concerned with threats or risks (e.g., from the failure of waste management techniques) rather than with predictable environmental impacts.

Many hazardous wastes are nondegradable or persistent in the environment. Environmental effects may thus be irreversible, and it could be necessary to consider management techniques that provide for the perpetual care of these wastes.

Some hazardous wastes are biologically magnified or have cumulative effects on organisms. Waste stream compositions are subject to substantial variation, and when the wastes contain multiple components, antagonistic and synergistic effects can occur. Although most of these characteristics may also be found in nonhazardous wastes, they are particularly significant in hazardous waste management analysis, as they make it difficult to determine the precise nature of the threats that are posed by hazardous wastes.

Because of the special characteristics of hazardous wastes, traditional approaches to the economic analysis of pollution control will often be inappropriate, and comprehensive cost-benefit or risk-benefit studies may be neither feasible nor warranted for many hazardous waste problems. Instead, the author proposes a methodology for the analysis of hazardous waste management alternatives that is comparatively simple to apply and that has modest data requirements. At the same time, the methodology encourages a decisionmaker to examine the sociological aspects of a situation and to evaluate the cost and effects of varying degrees of risk aversion. Since the methodology builds on a cost-benefit foundation, it could also be used to supplement a cost-benefit study to take into account those effects that are difficult to quantify.

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Determining control costs for hazardous waste management presents no special problems; the major analytical difficulty lies in the uncertainties associated with damage functions. Conventional analysis of environmental damages starts by determining pollutant emissions, evaluates exposures and consequent effects on organisms, and then attempts to place a dollar value on these effects. Instead, a central feature of the methodology presented in this report is the use of environmental *threat scenarios*. Each scenario is a hypothetical chain of events which results from some initiating event (such as an accident or exceptional weather conditions) and leads to an adverse environmental impact (such as contaminated drinking water). These scenarios could be derived from modeling studies, but they can also be based on previous experience, public fears, or assumptions of the worst possible consequences. Some of the effects of these threat scenarios may readily be valued using well established techniques, but others may prove difficult to translate into dollars. However, the mere description of plausible threat scenarios is valuable because it helps to identify the *parties-at-interest*, which are groups, firms, etc., that are affected in a common manner by some hazardous waste management alternative.

Identification of parties-at-interest is another key feature of the methodology, as it helps a decisionmaker to recognize differing attitudes and viewpoints on hazardous waste management. It also encourages him to consider equity, since it highlights the distribution of favorable and unfavorable effects. The methodology uses a simple conceptual model of the socioeconomic interaction process that focuses on the effects that hazardous waste management techniques will have on the parties-at-interest and their responses to these effects. These responses will in turn influence the set of outcomes that result from a specified approach to hazardous waste management. The report includes some broad indications of the likely attitudes and behavior of the parties-at-interest, derived from hazardous waste management practitioners and the literature. A decisionmaker should be able to supplement these data with his perceptions of any specific situations. The local viewpoint may be important, because responses of the parties-at-interest to environmental threats will depend on their *perceptions* of those threats, irrespective of the true probabilities and magnitudes.

Because hazardous waste management decisions involve value judgments, a decisionmaker must usually make the final choice among alternatives, examining them against the agency's objectives and deciding on preferred trade-offs. However, some alternatives can be eliminated because they are dominated by others, such as where both quantifiable and nonquantifiable costs are higher for one alternative than another, and the nature and distribution of the costs is similar for both. Ultimately, the critical aspect of decisionmaking will usually be to decide on an appropriate degree of risk aversion. Research on risk evaluation, i.e., determination of the acceptability of risks to society, has provided some useful background information on the public's perceptions of risk. However, this research cannot at present provide the specific guidance that a decisionmaker would need to choose between hazardous waste management alternatives. Deciding on an appropriate degree of risk aversion remains his most difficult problem.

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APPLICATIONS OF THE METHODOLOGY

The research described here is believed to meet the needs of analysts and decisionmakers for a simple methodology that can analyze a variety of hazardous waste management problems. The methodology is adaptable to specific situations, is firmly based on economic principles, and recognizes the sociological factors involved. When necessary, it can be used with comparatively limited information, but it can exploit more sophisticated data when these are available. Ultimately, however, it requires a decisionmaker to choose between screened alternatives.

The methodology has been demonstrated by application to two widely differing situations. In a hypothetical case (Section 6), a decisionmaker is required to choose between alternative techniques for the disposal of a single high-volume waste stream. In this example, analysis concentrates on the costs and threats associated with the various disposal techniques and the attitudes of the parties-at-interest to these techniques.

The second demonstration (Section 7) involves a case study of hazardous waste management in Oregon. Though this study would not be sufficiently detailed or comprehensive to provide definitive planning guidance to Oregon environmental agencies, the usefulness of the methodology should be evident from this wide-ranging analysis. In contrast to the first demonstration, simplification of the data to facilitate analysis is an important part of the procedure, and the use of scoring to weight the divergent interests and attitudes of the parties-at-interest is illustrated.

Both demonstrations show how the decisionmaker's task can be simplified. In the first case some options can be eliminated because they are dominated by others; in the Oregon case study, certain waste management approaches are eliminated through a series of paired comparisons. However, in neither case is the final decision clear-cut. In both cases, the decisionmaker must decide on an appropriate degree of risk aversion, and in the Oregon case, he must also subjectively balance several different considerations before he can come to a conclusion.

These two demonstrations illustrate both the width of possible applications and the potential value of the methodology as an aid to decisionmaking. Other potential applications include analysis of alternatives for the treatment or disposal of a particular type of waste (e.g., PCB's) at the regional or national level, and as an aid to comparing the nontechnical aspects of promising new disposal techniques with existing ones. Parts of the methodology could be of assistance in conducting a technology assessment on a new treatment or disposal technique. Furthermore, the methodology could be extended to assist in a wide variety of decisionmaking situations where costs and benefits cannot readily be compared and where sociological considerations are important.

RECOMMENDATIONS FOR FURTHER RESEARCH

The methodology has been demonstrated using comparatively simple examples. In practice, it should be capable of dealing with more complex situations; thus it should be tested and, if necessary, developed to fulfill a decisionmaker's needs under more complex circumstances. In particular, two of the links in the socioeconomic interaction model require further analysis. One linkage is between a policymaker's objectives and the approaches (i.e., strategies) that may be used to control hazardous wastes, and the other is between the approaches and the physical techniques that are actually employed. The latter is particularly important, since the use of nonregulatory policy elements such as incentives, subsidies, and penalties has been extensively analyzed in the literature, but their application to practical hazardous waste management situations needs further investigation.

The EPA's documentation and analysis of hazardous waste incidents is helpful in developing the threat scenarios used by this methodology, and it is recommended that this work be continued. (The threat scenarios developed in the demonstrations presented in this study benefited significantly from data on damage incidents collected and published by EPA.) In addition, it would be valuable if modeling studies (e.g., of leachate movement from landfills) included typical results for commonly encountered situations as an aid to the generation of threat scenarios.

Research on risk evaluation, and in particular on the psychometric expressed preference method (see Appendix F), is promising and should now be developed to provide more specific guidance for common environmental decisions.

SECTION 3

OVERVIEW OF HAZARDOUS WASTE MANAGEMENT

UNIQUE ASPECTS OF HAZARDOUS WASTE MANAGEMENT

As a first step toward developing a methodology for analysis of hazardous waste management alternatives, an economist must determine what is special about hazardous wastes (i.e., how does the management of these wastes differ from that of other wastes or pollutants). A clear-cut answer to this question is difficult to find, but the definition of hazardous waste provides some indications of its special characteristics. The hazardous waste definition used for this study classifies any waste as hazardous if it

> . . . [poses] a *substantial* present or potential *hazard* to human health or living organisms because such wastes are *nondegradable* or *persistent* in nature or because they can be *biologically magnified*, or because they can be *lethal*, or because they may otherwise cause or tend to cause detrimental cumulative effects. [Emphasis added.] (U.S. Environmental Protection Agency, 1974b:3)

This definition is based on the proposed Hazardous Waste Management Act of 1973. This statute was not enacted and was replaced by Subtitle C of the 1976 RCRA. Though the definition used in that Act is basically similar, it is slightly narrower and less illuminating for the purposes of analysis.

Several distinguishing characteristics relevant to economic analysis, and in particular to the potential damages associated with hazardous wastes, emerge from this definition. First, *a hazardous waste can pose a substantial or strong threat to man or the environment*. This statement suggests that hazardous wastes need more careful management than inert wastes or conventional pollutants, such as an organic waste that creates a biological oxygen demand (BOD). For example, when an organic waste is discharged into a river, the level of dissolved oxygen below the discharge point will fall as bacteria degrade the waste. However, little harm is done to the river, which will essentially return to normal downstream provided the BOD of the waste does not cause oxygen to fall to a level where fish are threatened, and provided nutrients released from the waste do not cause eutrophication (Freeman, Haveman, and Kneese, 1973). This example illustrates a management technique that may be acceptable for conventional pollutants (i.e., using the natural environment, particularly air and surface waters, to assimilate the waste, while accepting some local degradation). In contrast, for a hazardous waste the potential for damage may be so great or the environment may have so little assimilative capacity that uncontrolled discharge to the environment may be unacceptable.

Second, hazardous waste management will be more concerned with threats or risks as opposed to readily anticipated environmental impacts. If, for example, a paper mill discharges an organic waste to a river, the level of dissolved oxygen in the water will fall as previously described. The effect of discharging this waste to the river can be comparatively well predicted, and waste management decisions will be based, in part, on these effects. On the other hand, if a heavy metal waste is injected into a saline aquifer as a means of disposal, the intention is that the waste will remain in the aquifer and thereby cause no harm to the environment. One must, however, be concerned about threats that may arise from the use of this disposal method. For example, the saline aquifer may be interconnected with an aquifer used as a source of freshwater, which could become contaminated. Unlike the comparatively predictable effects from nonhazardous waste management techniques, it is usually difficult to estimate the probability that a hazardous waste threat will materialize, or to predict the magnitude or cost of the potential damage.

Third, hazardous wastes are often persistent or nondegradable. This quality is significant because (1) effects may be irreversible, and (2) time scales of interest can span more than one generation. Injecting a heavy metal waste into an aquifer may be essentially irreversible. Should the aquifer later be needed as a water or mineral resource, or be found to be interconnected with a freshwater source, decontamination might not be feasible. (In practice there are degrees of reversibility and irreversibility, and some irreversible changes are more significant than others. See Fisher and Krutilla, 1974.) Irreversibility can also introduce "option value" and associated concepts that relate to the benefits of avoiding foreclosure of future courses of action, or options. Furthermore, when the decisions of today affect future generations, it raises the difficult problem of whether or not it is appropriate to discount to reflect a reduced present value of costs that occur in the future. These two topics are discussed later.

Fourth, hazardous wastes include those that are biologically magnified or have cumulative effects. Biological magnification (or bioconcentration) is the ability of organisms to accumulate chemical contaminants to levels that are higher than those in their food sources. Such magnification can occur at several stages in the food chain, with the possible result that a contaminant that is present in insignificant concentrations at the lower end of the food chain could concentrate to toxic or lethal levels higher in the chain (Van Hook, 1978). An effect is cumulative when the impact on the organism depends on the entire history of exposure to the contaminant, rather than depending only on the immediate exposure. The difficulties of estimating damages due to exposure are compounded when bioconcentration or cumulative effects are present. However, this problem is not unique to hazardous wastes, as pollutants that are not normally regarded as hazardous may also have cumulative effects (such as that of urban air pollution on human health [Lave and Seskin, 1970]).

A final characteristic of hazardous wastes (one that is not apparent from the definition) is that the composition of wastes can vary substantially, not only because of different sources, but also from day to day for a given source. This factor complicates treatment to reduce the hazard and can

EPA-287 (Cin.)
(4-76)

inhibit resource recovery activities. Furthermore, it may mean that the degree of hazard posed by the waste is not well defined. Again, this characteristic is not unique to hazardous wastes.

To summarize, hazardous wastes are characterized by strong potential adverse effects, and their management may involve irreversible decisions and intergenerational time scales. The threats that these wastes pose to man and the environment are often difficult to specify because insufficient information is available. Waste composition variability, biological magnification, and cumulative effects compound the problem.

THE NATURE OF HAZARDOUS WASTES

The two basic aspects of a hazardous waste are (1) that it is an unwanted material, and (2) that the material has hazardous properties.

Wastes and the Environment

As Ayres and Kneese (1969) have pointed out, except for increases in inventory, all materials that enter the economy end up as wastes (or residuals, as they are commonly termed in the literature of environmental economics). The inputs to the economic system are fuels, foods, and raw materials, and these inputs are partly converted to final products and partly discarded as process residuals. After the final products have fulfilled their role, they too are discarded. Whereas final consumption products provide services to man, wastes usually provide disservices. They either consume resources to achieve disposal without environmental degradation, or they may cause pollution that results in such effects as fish kills, increased difficulty in water treatment, reduced public health, etc. (Ayres and Kneese, 1969).

Figure 1 illustrates the routes by which wastes can affect the environment. It also shows that there are several stages or points at which wastes can be controlled, as follows:

1. The waste stream from the manufacturing process can be changed to reduce the generation of hazardous wastes;
2. Some waste streams can be treated to reduce the hazard;
3. The initial disposition of the wastes in the environment can be controlled;
4. Subsequent interchange among environmental media can be restricted;
5. Interaction between the wastes and living receptors (i.e., organisms that may be affected by the wastes) can be controlled;
6. If the wastes have reached some living receptors, waste migration to other receptors, especially man, can be controlled.

EPA-287 (Cin.)
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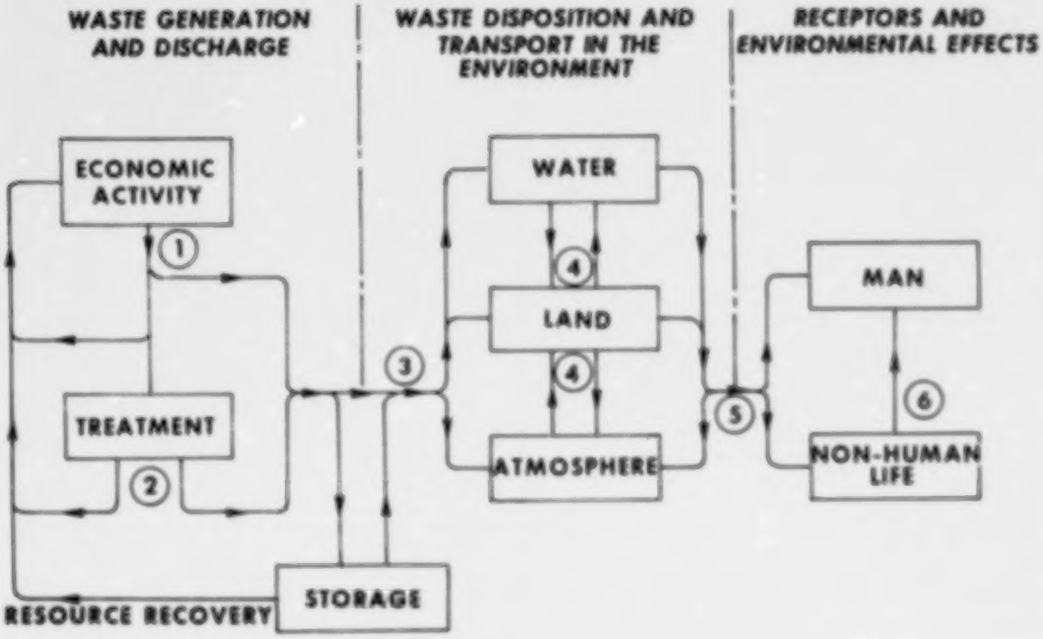
WASTE GENERATION AND DISCHARGE
WASTE DISPOSITION AND TRANSPORT IN THE ENVIRONMENT
RECEPTORS AND ENVIRONMENTAL EFFECTS
ECONOMIC ACTIVITY
①
TREATMENT
②
STORAGE
RESOURCE RECOVERY
③
WATER
④
LAND
④
ATMOSPHERE
⑤
MAN
⑥
NON-HUMAN LIFE

Figure 1. Routes by which hazardous wastes can affect the environment. (The numbers refer to points at which control can be exercised.)

Different waste disposal techniques provide varying degrees of control. For example, ocean dumping provides no control of marine life exposure to the wastes (i.e., no control at point 5 in Figure 1). On occasions such dumping has lead to the need to ban fishing and shellfish harvesting and to impound fish because of the danger to health posed by human consumption of contaminated marine life (Council on Environmental Quality, 1970). These actions constitute control at the last possible stage (i.e., point 6 of Figure 1). In contrast, disposal of wastes in deep mines should give rise to very little waste migration to air and water (i.e., good control at point 4). If, however, groundwater were to become contaminated as a result of mine disposal, it is unlikely that the groundwater would be used for irrigation or as a drinking water supply because of the depth of the aquifer. Thus in addition to control at point 4, mine disposal provides control at point 5.

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(4-78)

Whereas society's primary concern is to control the extent to which living organisms are exposed to hazardous wastes, in practice this can be achieved indirectly by controlling at points 1 through 4 as well as by direct control at point 5. However, there may be some wastes, especially those that are generated on an irregular basis (such as off-specification batches of products, cleanup wastes, discarded laboratory chemicals, etc.) for which control at point 1, and in some cases at point 2, is not feasible. This underscores the importance of controlling waste disposition in the environment (point 3), even though the strategy of control at earlier stages has been deemed to be more desirable by the U.S. Environmental Protection Agency (1976a).

Hazardous Attributes

According to Kohan (1975), hazardous substances generally fall into one or more of the following categories: Toxic to human and/or lower life forms, radioactive, flammable, reactive, explosive, oxidizing, irritating, genetically active, strongly sensitizing, and/or subject to bioconcentration. Though all classification systems reviewed by Kohan include toxicity as one criterion for designating a material as hazardous, there is considerable variation among different systems with respect to the choice of other attributes that can render a material hazardous. This variation may, in part, stem from the differing use orientations of the classification systems, and also from overlap between attributes. For example, flammable and explosive wastes are generally toxic, and many radioactive and some biological wastes are also toxic (U.S. Environmental Protection Agency, 1974b). A comparison of some of these classification systems is provided in Table 1.

The problem of deciding what makes a material hazardous is not, of course, restricted to the attributes to be considered, but also encompasses the potential magnitude or severity of the effect. While some materials are universally regarded as hazardous, there is a gray area in which authorities will disagree as to whether or not a material should be classified as hazardous. In many cases, the problem is compounded by inadequate data about the potential effects of the material on man and the environment.

The term hazardous may be regarded as having two connotations, one of which relates to the intrinsic properties of the waste itself, i.e., the amount of damage that it is capable of rendering to man or the environment. The second relates to extrinsic factors, such as the degree of exposure to the hazard, e.g., the quantities and circumstances surrounding the exposure (Battelle Memorial Institute, Pacific Northwest Laboratories, 1974, Vol.1). This discussion focuses on the intrinsic properties, but it will be noted that the quantity of waste (an extrinsic factor) is included in several of the systems summarized in Table 1.

Approaches for identifying hazardous materials fall into two general categories:

1. Specific rules or decision models for determining whether or not a material is hazardous;

TABLE 1. HAZARDOUS MATERIALS CLASSIFICATION CRITERIA*

	Criteria											
System	Toxicological	Flammability	Explosive	Corrosive	Reactivity	Oxidizing material	Radioactive	Irritant	Strong senitizer	Bioconcentration	Muta/tetra/carcinogenic	Sufficient quantity
Title 15, U.S. Code, Sec. 1261	X	X		X			X	X	X			X
CPSC-Title 16, CFR, Part 1500	X	X		X			X	X	X			X
Food, Drug, and Cosmetic Act	X									X	X	X
DOT-Title 49, CFR, Parts 100-199	X	X	X	X		X	X	X				X
Pesticides-Title 40, CFR, Part 162	X	X								X	X	
Ocean Dumping-Title 40, CFR, Part 227	X									X	X	X
NOISH-Toxic Substances List	X										X	
Drinking Water Standards	X									X	X	
FWPCA Sec. 304 (a)(1)	X									X	X	
Sec. 307 (a)	X									X	X	X
Sec. 311 (b)(2)(A)	X											X
Clean Air Act-Sec. 112	X							X			X	
California State List	X	X	X	X				X	X			
National Academy of Sciences	X	X			X							
TRW Systems Group	X	X	X	X			X			X		X
Battelle Memorial Institute [N.W.]	X	X	X		X	X	X	X		X	X	
Booz-Allen Applied Research, Inc.	X	X	X		X							X
Dept. of the Army	X											
Dept. of the Navy	X	X	X	X	X	X	X					
National Cancer Institute	X									X	X	X

* Source: Kohan, 1975:2.

2. Listings of materials deemed to be hazardous (the pure-compound approach).

There are difficulties associated with both approaches. The decision-model approach involves specifying levels of hazardous attributes, such as flash point, degree of toxicity, etc. A major problem is that it is not easy to decide upon the criteria to be used. As Flinn, Thomas and Bishop (1974) point out, most classification systems in use are deficient in that they focus on acute effects to the neglect of chronic effects, have a limited domain of concern, and are not designed to handle degradation products and synergistic effects when one material mixes with another.

The resources required for testing waste streams could be considerable, especially with respect to toxicity and genetic effects. Estimates of costs ranging up to $750,000 for animal toxicity testing of a single chemical have been suggested (Portney, 1978). Furthermore, variations in the composition of a given hazardous waste stream could make it difficult to obtain a representative sample.

Enormous resources could also be required to evaluate hazardous materials using the pure-compound approach. Flinn, Thomas and Bishop (1974) indicate that a quarter of a million chemical entities may be identified each year, and that several hundred are introduced into commercial use annually. The pure-compound approach also raises the problem of defining the concentration at which the presence of a given substance renders a waste stream hazardous. Furthermore, extrapolation from laboratory animal studies to effects on man is fraught with difficulties (Rall, 1975). These problems are compounded by the observation that low concentrations of some elements may be essential to certain forms of life, whereas higher concentrations may be toxic or lethal (Venugopal and Luckey, 1975). In addition, the approach does not allow for synergistic or antagonistic effects that may occur when mixtures of chemicals are present in a single waste stream.

Williamson (1975) includes a detailed discussion of the advantages and disadvantages of a number of versions of these two general approaches, and Battelle Memorial Institute, Pacific Northwest Laboratories (1974, Vol.1) comprehensively discusses the attributes that could make a waste hazardous.

Of various hazardous waste decision models, the Battelle model (Battelle Memorial Institute, Pacific Northwest Laboratories, 1974, Vol.1) is probably the best known. This model was included in the Report to Congress: Disposal of Hazardous Wastes (U.S. Environmental Protection Agency, 1974b) and is illustrated in Figure 2. While the usual purpose of decision models of this type is to provide a yes/no answer, some designate two degrees of hazard--for example, "dangerous" and "extremely hazardous" (Mehlhaff, Cook and Knudson, 1977). In addition, some models have been designed to produce a hazard rating or ranking. Klee (1976) has reviewed three such models and points out that because each represents a different evaluator's utility function, the correlation between results obtained from each model is poor.

EPA-287 (Cin.)
(4-76)

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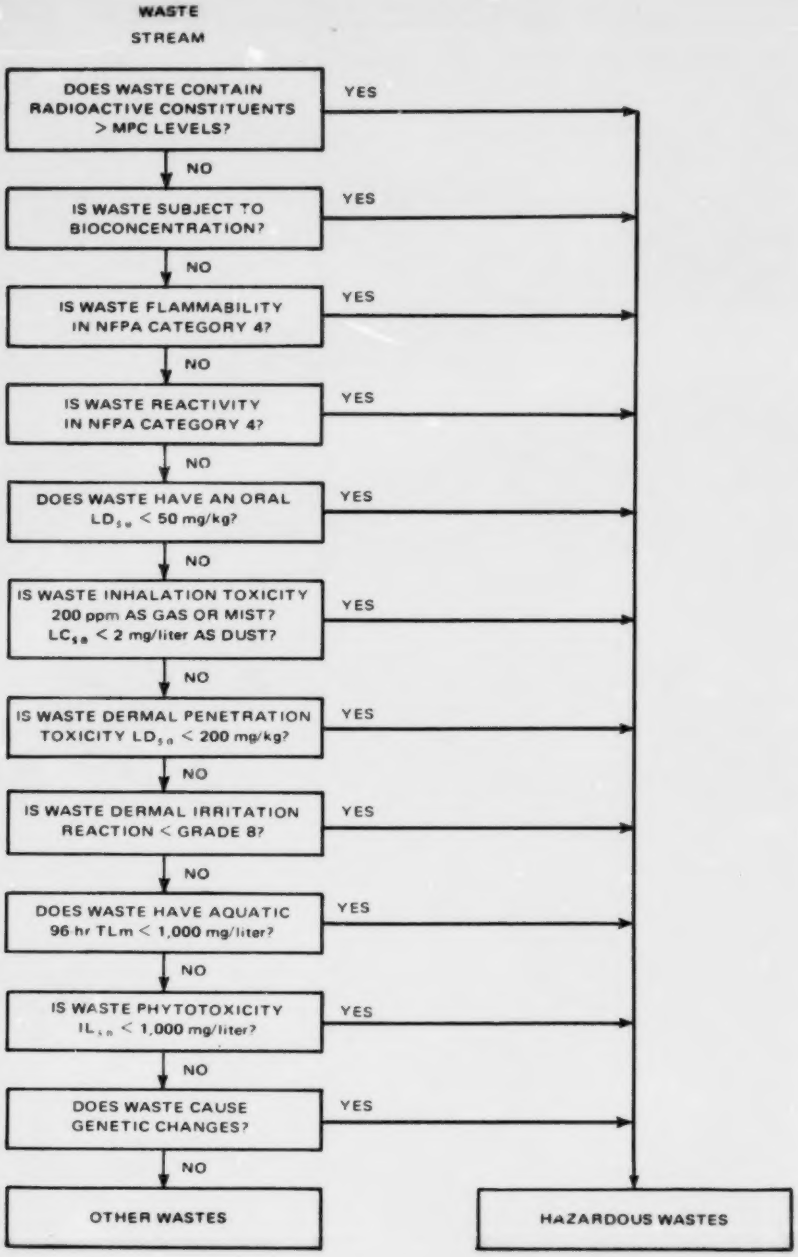
WASTE STREAM
DOES WASTE CONTAIN RADIOACTIVE CONSTITUENTS > MPC LEVELS?
YES
NO
IS WASTE SUBJECT TO BIOCONCENTRATION?
YES
NO
IS WASTE FLAMMABILITY IN NFPA CATEGORY 4?
YES
NO
IS WASTE REACTIVITY IN NFPA CATEGORY 4?
YES
NO
DOES WASTE HAVE AN ORAL LD_{50} < 50 mg/kg?
YES
NO
IS WASTE INHALATION TOXICITY 200 ppm AS GAS OR MIST? LC_{50} < 2 mg/liter AS DUST?
YES
NO
IS WASTE DERMAL PENETRATION TOXICITY LD_{50} < 200 mg/kg?
YES
NO
IS WASTE DERMAL IRRITATION REACTION < GRADE 8?
YES
NO
DOES WASTE HAVE AQUATIC 96 hr TLm < 1,000 mg/liter?
YES
NO
IS WASTE PHYTOTOXICITY IL_{50} < 1,000 mg/liter?
YES
NO
DOES WASTE CAUSE GENETIC CHANGES?
YES
NO
OTHER WASTES
HAZARDOUS WASTES

Figure 2. The Battelle hazardous waste decision model.

Source: U.S. Environmental Protection Agency, 1974b:57.

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Categories of Hazardous Waste

There are numerous ways of classifying wastes into generic groups. Bases include:

1. Hazardous attributes;
2. Material or chemical classifications (metals, organics, inorganics, etc.);
3. State of matter (gas, liquid, sludge/slurry, solid);
4. Geographic occurrence;
5. Industrial origin (e.g., either Standard Industrial Classification [SIC] or process origin);
6. Amenability to different forms of resource recovery, treatment and/or disposal;
7. Control by existing and/or proposed regulation;
8. The nature or significance of the threats that they pose to the environment.

Although similar to classification by hazardous attributes, the last approach (8) takes into account the waste's interaction with the environment (e.g., the ease with which it can be biodegraded, transported and/or changed to other forms by natural processes). It might also take account of the background level of the material in the environment.

With some classification schemes, there may be difficulties in allocating wastes to specific categories because of overlap problems--for example, if classified by hazardous attributes, a waste might be both toxic and flammable, or if classified by chemical composition, a waste might be basically organic but with low concentrations of heavy metals that cause it to be hazardous.

In practice, hybrid classification systems are often used; for example, Berkowitz, March, and Horne (1975) classify all industrial wastes (including, but not limited to, hazardous wastes) into 29 general waste streams based largely on the states of matter and the materials present or chemical composition. These same authors also propose a hierarchical classification system that has 21 dimensions, including such items as geographic and SIC origins, onsite treatment received, mode of transport to disposal, hazardous attributes, and properties related to recyclability and decomposibility (Berkowitz, March and Horne, 1975). In contrast, Perna (1977) suggests the use of only eight basic categories, one of which is "hazardous wastes."

In dealing with hazardous wastes, it may sometimes be useful to distinguish between wastes from different sources, as follows:

1. Industrial process wastes;

2. Radioactive wastes;

3. Hospital wastes (pathological);

4. Chemical laboratory wastes;

5. Surplus pesticides and pesticide containers;

6. Obsolete explosives;

7. Chemical and biological warfare wastes;

8. Other special wastes.

These distinctions are made on the grounds of the approaches that may be used to control the disposition of the wastes. Each type of waste may call for a different control method. For example, radioactive wastes are already subject to different regulations than chemical wastes, while regulations developed to deal with large quantities of industrial process wastes might be very cumbersome if applied to small quantities of laboratory wastes or empty pesticide containers.

Although post-consumer wastes undoubtedly contain hazardous components on occasions, they are not usually regarded as a source of hazardous waste. In contrast, mill tailings can have concentrations of heavy metals that are in excess of background levels and could therefore pose a hazard (Midwest Research Institute, 1975). However, because of the large quantities of materials involved, there are few feasible management alternatives for such wastes and hence they were not specifically considered in this study.

Treatable and Nontreatable Wastes

Although much general analysis can apply to all hazardous wastes, there is one hazardous waste classification that can usefully be employed in general policy or planning studies--whether a waste is "treatable" or not. A treatable waste can readily be detoxified or rendered harmless by physical, chemical, or biological means; whereas a nontreatable waste cannot readily be detoxified. For example, waste sulfuric acid and phenol-contaminated wastewater may qualify as hazardous wastes under various classification schemes. However, sulfuric acid may be neutralized by reaction with a low-cost, widely available alkali such as lime, and phenol is readily biodegradable at low concentrations (Rosfjord, Trattner, and Cheremisinoff, 1976). Thus these "treatable" wastes may usually be simply and inexpensively rendered harmless.

In contrast, the toxic properties of a heavy metal are fundamental to that element, and the waste cannot be treated to render it harmless. Hence if a waste contains heavy metals in significant quantities, it is necessary to find ways to prevent the release of these elements if the environment is to be protected. (This could, for example, be achieved by physical containment or by insuring that the waste remains in a highly insoluble form.) However, a "nontreatable" waste of this type remains a permanent threat, and must be considered a candidate for perpetual care, requiring continuing monitoring to insure that its disposal has not affected the environment. This is an important distinction from a "treatable" waste.

Inevitably, there is a zone of uncertainty or overlap between the two categories. For example, PCB's exhibit serious chronic toxicity, are subject to bioaccumulation, and are highly persistent in the environment (U.S. Environmental Protection Agency, 1976b). However, as synthetic organic compounds, they are capable of degradation to a harmless form by incineration. Unfortunately, the required incineration parameters (high temperature and long dwell time) are such that effective thermal degradation is very costly, especially compared with simple treatments of the type discussed above. Hence waste PCB's do not readily fit into either the "nontreatable" or "treatable" category, as they are technically treatable, yet economic considerations may result in their not being treated. For this waste, the most viable alternative might be some form of perpetual care.

TECHNIQUES FOR THE MANAGEMENT OF HAZARDOUS WASTES

The term "technique" is used in this report to denote a technical means of changing, treating, or disposing of a hazardous waste. The term is restricted to direct physical activities and does not imply anything about its economic or social effects or the policies that might encourage or discourage the use of that technique.

The techniques that are available fall into four groups, as follows:

1. Techniques that change the composition or magnitude of the waste stream itself;

2. Techniques that recover values (materials or energy) from a given waste stream;

3. Techniques that treat the waste stream in order to render it less harmful;

4. Techniques that store or dispose of the waste.

A waste may be sequentially subjected to more than one technique; for example, a disposal technique may be preceded by some form of treatment. The term "disposal" (or sometimes "ultimate disposal") is commonly used to denote removal of the waste from the immediate location of generation to some other location where it is put into permanent storage (as in a landfill), diluted or dispersed (as may occur in ocean dumping). The available techniques are listed in Table 2 and are described in Appendix A.

LEGISLATIVE BACKGROUND OF HAZARDOUS WASTE REGULATION IN THE UNITED STATES

In the past decade, significant advances have been made in legislative controls of most of the major sources of environmental degradation.

EPA-287 (Cin.)
(4-76)

TABLE 2. TECHNIQUES FOR THE MANAGEMENT OF HAZARDOUS WASTES*

Technique	Location†	Comment
Change in waste streams:		
Process change	Onsite	To generate wastes that are less hazardous
Source reduction	Onsite	To generate less hazardous waste
Waste separation	Usually onsite	To separate hazardous waste from nonhazardous waste
Resource recovery:		
Materials recovery	On/offsite	
Energy recovery	On/offsite	
Treatment to reduce hazard:		
Physical treatment	On/offsite	Variety of processes available (see Table A.1.)
Chemical treatment	On/offsite	
Biological treatment	On/offsite	
Thermal treatment	On/offsite	
Encapsulation	--	To immobilize wastes
Storage or disposal:		
Land application	Usually offsite	
Landfilling	On/offsite	
Mine disposal	Usually offsite	
Lagooning	On/offsite	For storage, liquid volume reduction by evaporation; may also involve treatment
Deep well injection	On/offsite	Liquids only
Ocean dumping	Offsite	
Engineered storage	Usually offsite	
Space disposal	Offsite	

* Source: Adapted from U.S. Environmental Protection Agency, 1974b; Kovalick, 1975, Appendix A; and other sources.

† Location at which technique is used, relative to site of waste generation.

Amendments to the Clean Air Act in 1970 (PL 91-604) established a system of air quality and emissions standards that has resulted in marked reduction of pollutants discharged into the air. The Federal Water Pollution Control Act, passed in 1972 (PL 92-500), instituted a similar system for controlling effluents passing into the Nation's watercourses. Both of these statutes include provisions designed to prevent hazardous pollutants from being dumped into the respective environmental media with which they are concerned. Hazardous air pollutants are controlled by establishing stringent limitations for stationary source emissions of designated pollutants (Arbuckle et al., 1976). Discharges of hazardous or toxic pollutants into surface waters from point sources are controlled in several different ways in the Federal Water Pollution Control Act, but the basic concept is to establish limitations on the amounts and types of these effluents. In some cases, standards of performance are set for certain industries, while effluent standards for hazardous pollutants are set in others (U.S. Environmental Protection Agency, 1974b).

Ocean dumping, commonly used in the past, has now been virtually eliminated as a technique for the disposal of hazardous wastes (U.S. Environmental Protection Agency, 1977a). Under the Marine Protection Research and Sanctuaries Act of 1972 (PL 92-532, as amended), the dumping of any radiological waste is prohibited; and a permit is required before any other material can be dumped. It is the policy of the Act to regulate all ocean dumping and to prevent or strictly limit the ocean dumping of any material that would adversely affect the marine environment (U.S. Environmental Protection Agency, 1977a). Also, in 1974, the United States ratified the 1972 International Convention on the Prevention of Marine Pollution by the Dumping of Wastes and Other Matter. This convention prohibits the deliberate ocean disposal of certain waste materials (which are additional to those considered above) and requires that special care be taken in issuing permits for other specified materials (U.S. Environmental Protection Agency, 1977e).

In addition to the legislation mentioned above, there are 13 other Federal statutes that have some bearing on the treatment, storage, transportation, and handling of hazardous wastes (U.S. Environmental Protection Agency, 1974b). Much of this legislation applies to specific wastes or categories of wastes (explosives, for example).

At the beginning of this decade, it was realized that (a) increasingly stringent control of air and surface water pollution was diverting wastes to various forms of land disposal that were largely uncontrolled, and that (b) although some aspects of hazardous wastes were addressed piecemeal by a variety of Federal and State statutes, some comprehensive control was needed. These two forces prompted Congress to enact Section 212 of the Resource Recovery Act of 1970 (PL 91-512), which directed EPA to undertake a study to better identify the nature and scope of the hazardous waste problem, with special orientation toward establishing a system of national disposal sites for hazardous wastes. The resulting report, delivered to Congress in June 1973 (U.S. Environmental Protection Agency, 1974b), strongly emphasized the need to regulate hazardous wastes in a comprehensive manner.

The initial legislation proposed subsequent to this report provided for identification of hazardous wastes, establishment of standards for treatment and disposal of such wastes, and establishment of guidelines for State programs for implementing such standards. It did not, however, propose a system of Federally controlled national disposal sites. After several years of deliberation, similar legislation was finally passed in October 1976 as Subtitle C of the RCRA (PL 94-580). The objectives of this Subtitle are as follows:

> The basic thrust of the hazardous waste title, is to identify what wastes are hazardous and in what quantities, qualities, and concentrations and the methods of disposal which may make such wastes hazardous. The title requires that the Administrator promulgate regulations applicable to generators. Such regulations include recordkeeping, informing those that transport or dispose of such hazardous waste of the characteristics of such waste and the initiating of a manifest system so that the waste generated can be traced to the site of ultimate disposal. . . .
>
> Regulations are imposed on transporters of hazardous waste. Most important is the initiation of a manifest system so that the hazardous waste can be traced from the generator to a facility that has an approved permit. . . .
>
> Other regulations required to be promulgated relate to those who treat, store or dispose of hazardous waste. Such regulations are to consist of compliance with the manifest system, recordkeeping requirements and inspections.
>
> The Administrator is also empowered to recommend methods of treatment, storage or disposal of hazardous waste, and the operation of such facilities, to assist the operators in safely handling such hazardous waste.
>
> Finally, those who store, treat, or dispose of hazardous waste are required to receive a permit either from the Administrator or from the appropriate state agency authorized by the Administrator to grant such a permit. . . . [Emphasis added.]
> (U.S. House of Representatives, 1976:6,7)

Prior to the passage of the RCRA, only a limited number of States had comprehensive hazardous waste legislation (Lehman, 1976), although at least 25 had legislation or regulations that provided some control (U.S. Environmental Protection Agency, 1974b). EPA is currently promulgating regulations that will insure adequate management throughout the United States. These regulations are designed to provide cradle-to-grave control of hazardous wastes. The basic management philosophy is to control the disposition of hazardous wastes, and to provide adequate environmental protection without specifying the technologies that must be used. One of the most difficult problems has been to define hazardous waste. The regulations specify that certain materials are hazardous, whereas tests are utilized to determine the status of some waste streams.

EPA-287 (Cin.)
(4-76)

PREVIOUS RESEARCH ON HAZARDOUS WASTE MANAGEMENT

Prior to 1970, when Congress passed Section 212 of the Resource Recovery Act, little attention had been paid to the problems of hazardous wastes, although the risks and procedures involved in the transportation of hazardous materials had been studied (Smith, 1976). Following the 1970 Resource Recovery Act, EPA commissioned a number of wide-ranging research studies.

In an initial study, Booz-Allen Applied Research Inc. (1972) compiled a candidate list of hazardous materials and attempted to assess the nature and magnitude of the problem. This was followed by an in-depth study, which included developing profile reports (summarizing quantities generated and hazardous properties) on over 500 potentially hazardous materials and analyses of a variety of treatment and disposal techniques that might be used in hazardous waste management (Ottinger et al., 1973). All of this work was predisposed toward the concept of a system of national disposal sites for hazardous waste, and another EPA-sponsored study examined alternative approaches to the use of such disposal sites. Three basic approaches were considered: Onsite waste processing (i.e., treatment and/or disposal of the waste at the location where it is generated), offsite processing at some regional hazardous waste facility, and a combination of onsite pretreatment and offsite treatment and disposal. This study examined the process economics and other considerations associated with these alternatives for a number of common waste streams that were regarded as strongly hazardous and concluded that most should be processed at national disposal sites (Arthur D. Little, Inc., 1973). Meanwhile, in *Program for the Management of Hazardous Wastes*, Battelle Memorial Institute, Pacific Northwest Laboratories (1974) estimated the quantities of hazardous waste generated in the United States and made a detailed examination of the feasibility of a system of national disposal sites, including conceptual designs, etc.

The results of this series of studies were integrated into the *Report to Congress: Disposal of Hazardous Wastes* (U.S. Environmental Protection Agency, 1974b). In this report EPA concluded that for the most part, hazardous wastes were disposed of using low-cost methods that did not provide adequate environmental protection. The technology to adequately manage most hazardous wastes was found to be available, but adequate management is often costly. Hence the waste generators frequently have an economic incentive for inadequate management.

The *Report to Congress: Disposal of Hazardous Wastes* indicated that about 9 million tonnes (10 million short tons) of nonradioactive hazardous wastes were being generated annually in the United States, increasing at 5 to 10 percent per year. About 90 percent of these wastes were in liquid form, the remainder being solids, sludges, and slurries. (Emissions of hazardous materials to the air were not considered in these studies as such emissions were already controlled under Section 112 of the Clean Air Act as amended in 1970.) About 60 percent of the wastes were organic materials. Virtually all of these wastes were industrial process wastes, and practically all of them were toxic (U.S. Environmental Protection Agency, 1974b).

EPA-287 (Cin.)
(4-76)

Subsequently, EPA commissioned detailed studies on the 14 industries that were believed to contribute the bulk of all hazardous process wastes (Abrams, Guinan, and Derkics, 1976; Arthur D. Little, Inc., 1976; Battelle-Columbus Laboratories, 1976; Foster D. Snell, Inc., 1976a; Gruber and Ghassemi, 1975; Jacobs Engineering Co., Inc., 1976; McCandless et al., 1975; Leonard et al., 1975; SCS Engineers, Inc., 1976; Shaver et al., 1975; Swain, 1976; WAPORA, Inc., 1976, 1977a, 1977b). Each of these studies characterized the structure of the industry, estimated the total process wastes generated (both at the time of the study and in the future), identified the portion of the waste that was considered to be potentially hazardous, determined the disposal methods currently in use, and estimated direct control costs for various levels of treatment and disposal technology. The results of these studies, which are summarized in Table 3, showed that these industries generated nearly 29 million tonnes (32 million short tons) of hazardous waste in 1974. This is expected to increase to 38 million tonnes (42 million short tons) by 1983, largely because of residues from additional air and water pollution controls. A pervasive problem with this research has been that of defining a hazardous waste. In each of the 14 industries studied, the contractor chose the definition employed, which was not necessarily consistent with that used for the Report to Congress: Disposal of Hazardous Wastes (U.S. Environmental Protection Agency, 1974b). The estimates in the latter report of 9 million tonnes (10 million short tons) of wastes considered potentially hazardous were generated using the Battelle hazardous waste decision model (U.S. Environmental Protection Agency, 1974b). However, the problem of determining how much hazardous waste is generated is not restricted to the choice of criteria. In addition, waste stream magnitudes and concentrations of constituents are uncertain or subject to variation, and the toxicity and genetic effects of the components may be ill-defined, especially in the presence of other components. Consequently, the difference (a factor of three) between the two totals is not unreasonable.

For some industries, additional studies have been completed on alternative control technologies that might be employed and on the economic effects (e.g., changes in product prices and plant closings) of possible hazardous waste management regulations (e.g., Versar, Inc., 1977; Williams et al., 1976). Another study examined the structure and capacity of the independent hazardous waste management industry. In 1975, this was found to consist of about 95 firms operating 110 facilities. Annual capacity was determined to be about 7.3 million tonnes (wet basis), but only about half that capacity was being used (Foster D. Snell, 1976b; also see Farb and Ward, 1975). Comparison of these data with those for total generation of hazardous wastes (Table 3) supports EPA findings that most industries dispose of their hazardous waste locally to the land and that only a small proportion of this waste is handled in a manner that EPA regards as environmentally adequate (U.S. Environmental Protection Agency, 1977b).

Other Federal research has included the collection and analysis of data on hazardous waste incidents (situations in which significant environmental degradation or damage to health or life has occurred), and numerous supporting studies have been conducted on hazardous waste treatment and disposal technologies. This research is discussed in Appendices A and B.

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TABLE 3. POTENTIALLY HAZARDOUS WASTES GENERATED IN THE UNITED STATES*

	Quantity of waste generated (million tonnes per year)			
	1974		1983	
Industry category	Dry	Wet	Dry	Wet
1. Batteries	0.005	0.010	0.105	0.209
2. Inorganic chemicals	2.000	3.400	2.800	4.800
3. Organic chemicals, pesticides and explosives	2.150	6.860	3.800	12.666
4. Electroplating	0.909	5.276	1.751	5.260
5. Paint and allied products	0.075	0.096	0.105	0.145
6. Petroleum refining	0.625	1.757	0.811	1.888
7. Pharmaceuticals	0.062	0.065	0.104	0.108
8. Primary metals smelting and refining	4.454	8.335	5.536	10.418
9. Textile dyeing and finishing	0.048	1.770	0.179	0.716
10. Leather tanning	0.045	0.146	0.068	0.214
11. Special machinery	0.102	0.163	0.157	0.209
12. Electronic components	0.026	0.036	0.050	0.108
13. Rubber and plastics	0.205	0.785	0.299	1.204
14. Waste oil re-refining	0.057	0.057	0.144	0.144
Total	10.763	28.755	15.909	38.089

* Source: U.S. Environmental Protection Agency, 1977b:14.

Public input to hazardous waste management decisionmaking was solicited via four public meetings on hazardous waste management held in December 1975 (Corson, 1976). EPA has prepared a synopsis of these meetings (U.S. Environmental Protection Agency, 1976c), and Edelman et al. (1976) have analyzed the issues that were raised. In addition, meetings were held early in 1977 in each of the 10 EPA regions on implementation of the RCRA (U.S. Environmental Protection Agency, 1977d). An early study attempted to gauge likely attitudes of the public toward the national disposal site concept (Lackey, Jacobs and Stewart, 1973), and is discussed later.

Other Research

EPA has encouraged the States to conduct hazardous waste generation and disposal surveys as a preliminary stage toward formulating hazardous waste management plans. Various EPA publications directed toward these ends are available (Porter, 1975, 1976; U.S. Environmental Protection Agency, 1977b). Although a number of statewide and some regional and local surveys have been initiated, several have met with only limited success because of poor

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PAGE NUMBER

response from the generating firms. This difficulty has been compounded by the absence of an accepted and easily applied definition of hazardous waste. On the other hand, California has obtained excellent responses using a carefully designed and strongly followed-up survey technique on a county basis (Sanders, 1977).

General Findings on Previous Hazardous Waste Research

The author has concluded that the following generalizations may be made about previous hazardous waste research:

1. It has emphasized process wastes (as opposed to post-consumer or post-industrial wastes) and has not to any significant extent considered hazardous emissions to the atmosphere;

2. It has emphasized toxic and radioactive wastes (as opposed to flammable wastes, for example);

3. It has been demonstrated that precise and comprehensive definition of hazardous waste is difficult and subject to disagreement among authorities;

4. It has had a technological emphasis and has not to any great extent attempted to consider public attitudes toward waste management alternatives;

5. It has been oriented toward end-of-pipe solutions, and much of it was predisposed toward the national disposal site concept;

6. It has largely been conducted on an industry-by-industry, waste-by-waste basis and has shown that virtually every industry has a number of unique features with respect to hazardous waste management;

7. It has made evaluations largely in terms of direct control and disposal process economics and has generally not evaluated any indirect costs (such as environmental costs) or social impacts, nor has it considered the implications of differing attitudes toward risk-taking;

8. Its philosophy of equity has been, "Let the polluter pay.";

9. The studies have used generalized analysis and have tended to specify what their authors regard as the best solution, rather than dealing with specific problems and displaying the pros and cons of alternative solutions.

This summary of previous research on hazardous wastes is not intended as criticism, but is presented to identify gaps in our knowledge and pitfalls to be avoided. Again, it must be emphasized that these are general findings to which there may be certain exceptions.

Thus to date, economic analysis has not addressed the problem of selecting socially optimal hazardous waste management policies, except in an extremely general way (Talley and Albrecht, 1974). No significant attempt has been made to apply the techniques of cost-benefit or risk-benefit analysis to hazardous waste management. And though decisionmakers have not been insensitive to public attitudes, no ways have been found to factor them systematically into the process of hazardous waste policy selection. This report represents a step toward rectifying these omissions.

EPA-287 (Cin.)
(4-76)

SECTION 4

ECONOMIC AND SOCIAL ASPECTS OF HAZARDOUS WASTE MANAGEMENT

COST-BENEFIT AND RISK-BENEFIT ANALYSIS FOR ENVIRONMENTAL PROBLEMS

Established Applications

Techniques of cost-benefit and risk-benefit analysis are well developed, and have already been applied to several classes of environmental problems.* For example, cost-benefit analysis has been applied to air and water pollution control programs (Peskin and Seskin, 1975), while risk-benefit analysis has been used to compare alternative means of generating electric power (Barrager, Judd, and North, 1976).

Cost-benefit analysis is usually used to determine whether or not a project or an activity should be undertaken, which requires that the total benefits conferred should exceed the total costs involved. At the same time, cost-benefit analysis frequently involves determining the optimum scale of activity, i.e., the project scope at which the net benefit (total benefits less total costs) is maximized. Analysis of this type could be appropriate to deciding whether or not to create a park or to preserve a natural environment as a wilderness area.

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* In cost-benefit analysis, all the costs of a proposed action, including social and environmental costs, are summed and compared with the benefits arising from the action. Since costs and especially benefits can involve effects (such as environmental changes) for which there is no established marketplace, values for effects must frequently be imputed from other indicators. (This is discussed with reference to hazardous wastes in Appendix C.) The distinction between cost-benefit and risk-benefit analysis is not clear-cut. The term "risk-benefit analysis" is often applied to a category of cost-benefit analysis in which risks to life and health are an important component of the costs (e.g., National Academy of Engineering, 1972). It would not be applied to an analysis in which the risks were purely economic (e.g., where there is construction cost uncertainty or where there is doubt about the magnitude of the project benefits). Some authors dealing with risks to life retain the term "cost-benefit analysis" (e.g., National Academy of Sciences, 1977), whereas others use the term "cost-risk-benefit analysis" to suggest that the costs include both conventional costs and risk-related ones (e.g., U.S. Atomic Energy Commission, 1974).

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In a pollution control analysis, however, the analyst's terms of reference do not usually permit questioning the desirability of the economic activity that generates the pollutant. In many cases the activity is already in existence. Hence analysis considers only costs associated with pollution, and the conventional economic approach to pollution control becomes that of determining the optimum level of pollution and devising a policy that results in that level. Conceptually (but not in practice) this process is straightforward and involves controlling the discharge of the pollutant to the level that minimizes the total cost (i.e., Q1 in Figure 3). In this case it is implicity assumed that overall, the benefits of the activity outweigh the costs.

Risk-benefit analysis can examine whether or not an activity that involves risk should be undertaken or allowed. It could, for example, be used to decide whether or not a particular toxic substance should be used in a given application (Provenzano, 1973). This involves comparing the benefits of such use with the risks incurred. In some risk-benefit analyses, however, the net benefit of the activity is assumed to be positive, and the analysis is used to compare alternative ways of achieving the objective. For example, in assessing alternative means of generating electric power, the expected numbers of accidents in mining and transportation have been estimated and have been expressed as a cost (U.S. Atomic Energy Commission, 1974). The effects of air pollution (e.g., sulfur dioxide) on health and property could also be included in the same way, although in practice there are major difficulties involved in predicting the effect of airborne pollution on human health (Sagan, 1972; Goldstein, 1975). The probability and results of accidents could also be estimated, as in the Rasmussen report on major accidents in nuclear power plants (Rasmussen, 1975).

Most risk-benefit assessments use expected values to describe the risks. By assigning probabilities and economic values to the risks, an expected value of total damage or cost can be obtained, and the least cost means of achieving a specified objective can thereby be determined. Alternatively, the expected value approach can allow the optimum level of exposure to risk (e.g., radiation exposure from mammography [National Academy of Sciences, 1977]) to be determined in a manner that is analogous to Figure 3. This is comparatively simple where large numbers of individuals are exposed to risks that are statistically well defined, but the approach does not allow for a decisionmaker's aversion to risk-taking which could be particularly important where there are low probability risks with major consequences (e.g., nuclear power plant disasters). (One solution to this difficulty would be to specify a decisionmaker's utility function to build in a degree of risk aversion--see Appendix F.)

Tihansky and Kibby (1974) make a conceptual extension of the expected value approach by introducing confidence intervals and comment that a risk-averse decisionmaker might base his decisions on values that are displaced from the means. For example, if asked to approve the manufacture of a toxic substance, he might choose the upper decile for damage costs and the lower decile for benefits. Of course, the difficulty with this approach is to determine all the necessary data.

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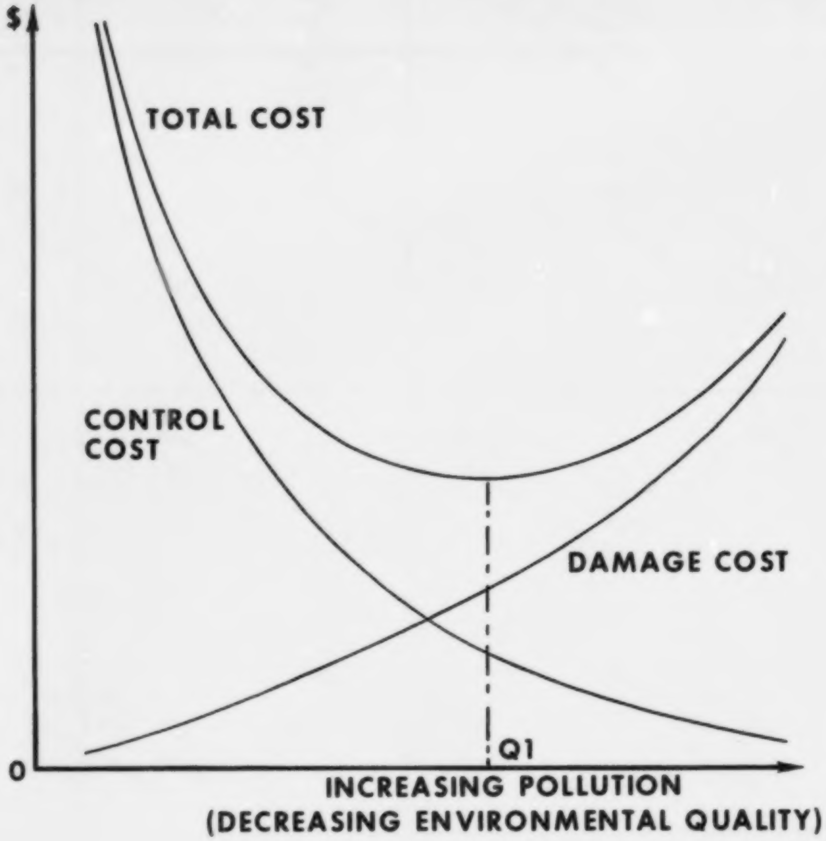

Figure 3. Conventional economic approach to pollution control.

Though the basic approach in cost-benefit and risk-benefit analyses is to express all effects in terms of a common measuring rod (the dollar), studies rarely succeed in placing dollar values on all the environmental effects. Some authors have endeavored to make up for omissions by listing predictable impacts, such as annual quantities of effluents and wastes requiring disposal. The difficulties that may be encountered in attempting to perform a comprehensive cost-benefit or risk-benefit analysis are discussed by Fischhoff (1977) in an excellent critique of the techniques.

Application to Hazardous Waste Management

From an analytical viewpoint, there are significant differences between the types of pollutants and risks discussed above, and those associated with most hazardous waste problems. The conventional economic approach to pollution control (Figure 3) arrives at a least cost solution by changing the control measures used so that the quantity of pollutant released to the environment varies. This approach assumes a single pollutant (or index of pollution, such as BOD) as the independent variable (the abscissa in Figure 3). Except in cases such as waste treatment for a single industry, hazardous waste management techniques (landfilling, for example) usually involve many different wastes that may have different hazardous attributes. Hence, in many cases, a variable representing the magnitude of a pollution threat would be difficult to generate. In the absence of a suitable index, analysis would have to be undertaken on a waste-by-waste basis and would need to consider interactions between wastes. This would require numerous data that would rarely be available, and the problem would be complicated by the variability in composition of many hazardous wastes.

Further difficulties arise with the damage function. It may not be desirable to use an expected value or similar measure of damage cost. There are two arguments against use of an expected value; risk aversion has already been mentioned, and the second is that the public perception of a risk may be more important than its true probability and magnitude. These issues are discussed later.

However, even if expected values are used, compare what would be involved in making a hazardous waste risk-benefit analysis with a risk-benefit analysis of alternative means of generating electric power (e.g., Barrager, Judd, and North, 1976; U.S. Atomic Energy Commission, 1974). Most generation of electric power uses a limited number of comparatively uniform technologies (e.g., coal, oil, gas and certain nuclear fuel cycles). Likewise, the fuel extraction technologies are of limited diversity, and most have been established for a sufficient length of time to provide good data on risks such as occupational injuries and adequate data on potential environmental damages such as acid mine drainage. The uniformity of the technologies and the magnitude of the resources that might be committed to them, together with the availability of comparatively good data, can warrant expenditure of considerable effort to make comparative risk-benefit analyses. For example, the Rasmussen (1975) study of accident risks in two types of nuclear power plants cost some $4 million.

In contrast to the electric power situation, hazardous wastes are highly diverse, and while some of the treatment and disposal technologies are comparatively uniform, the environmental conditions associated with disposal techniques (such as precipitation, soil and aquifer properties) are highly variable. Hence, the threats that hazardous wastes pose to man and the environment can vary considerably with the circumstances. It will frequently be difficult to predict the probability of their occurrence, and it may also be hard to project the damage if a threat does materialize. This diversity implies that even if feasible to comprehensively and accurately characterize the threats that might arise from hazardous waste management alternatives would often take considerable resources.

Though detailed analysis (such as is used in conventional cost-benefit and risk-benefit analyses) may be possible and justified for some hazardous waste problems, there will be many for which it is not. This may occur because the necessary data cannot realistically be generated, or because the effort that would be required would be out of proportion to the scope of the problem (as measured by the worst case damage potential, or the cost of achieving a high level of control). What is needed is a methodology for evaluating hazardous waste management alternatives that recognizes the principles of risk-benefit analysis but that is simple to apply and does not require extensive data. This study attempts to provide a suitable methodology. A key component of the approach proposed is the identification of threats and the use of threat scenarios to describe the possible adverse consequences of hazardous waste management techniques.

THREATS THAT MAY ARISE FROM HAZARDOUS WASTES

In the analysis of hazardous waste management alternatives, the damage or risk component can be regarded as a series of different threats of adverse events that may arise from the use of various control techniques. The term "threat" is used because, in most cases, there is some probability (not necessarily known) of the specified event occurring. It may occur soon, later, or never; and if the threat does materialize, the magnitude of the effect may also be uncertain. For example, there is a threat that a lagoon containing hazardous waste may overflow because of exceptional rainfall. The timing and the size of the spill (and hence its effects) cannot be forecast, although in this case they could quite readily be expressed in probabilistic terms.

Identification of Threats

A threat is always present, but for the threat to materialize, some sort of initiating event is required. Many initiating events are well-defined specific incidents such as an industrial accident or an unlikely environmental occurrence (e.g., an earthquake) that can trigger a threat mechanism. However, a threat may also arise from inadequate design or poor practice, such as the operation of a landfill in such a way as to provide no environmental protection from hazardous leachates. A broad (as opposed to detailed) list of initiating events is given in Table 4, which also lists threat mechanisms and outcomes.

Threat mechanisms define the nature of the threat itself, and may be sequential or hierarchical (for example, fire could lead to explosion, or vice versa). Outcomes are the end results of threats. A threat may not always carry through to result in an observable or measurable adverse outcome, such as poisoning of some life forms. However, even where there is no outcome of this type, there may well be a loss of some potential options. For example, a toxic leachate could contaminate an aquifer that is used as a drinking water source. In this case, the outcome would probably be poisoning, and alternate water supplies would be needed. If, however, the aquifer (or at least the part that was contaminated) was not used for any sort of water supply, no poisoning would result, but the option of using the aquifer as a freshwater source would be lost unless decontamination were

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TABLE 4. ENVIRONMENTAL THREATS IN HAZARDOUS WASTE MANAGEMENT

Initiating events:

Geologic event (e.g., earthquake, erosion, change in aquifer, meteorite impact)
Climatic event (e.g., unusual storm, flood, lightning, etc.)
In-plant accident
Transport accident
Sabotage
Operational failure or error (man caused)
Inadequate design or poor practice (including corrosion)

Threat mechanisms:

Spillage
Overflow
Containment failure
Leaching
Unintentional or unwanted mixing
Unintentional or unwanted contact
Fire
Explosion
Ground movement or shock waves
Unintentional or unwanted emissions (to air)
Odor
Vector
Bioconcentration

Outcomes:

Destruction of life (man, fauna, flora)
Destruction of real property
Poisoning
Modification of an ecosystem (by changing balance of species)
Olfactory insult

Loss of option(s)

Note: Aesthetic degradation has not been listed as a specific outcome as it is an aspect of other outcomes

possible. Similarly, an area of barren ground could be contaminated by a spill without causing destruction of life, but the contamination could preclude various future uses.

By combining initiating events, threat mechanisms and outcomes, a series of possible threats can be developed. For example, inadequate landfill design results in a leachate containment failure, which causes contamination

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of groundwater (by mixing), which leads to livestock poisoning. Numerous such threats could be identified, depending on the degree of comprehensiveness required. Thus in the example above, the leachate damage could lead to chronic or acute poisoning of flora, fauna, man, etc.

Figure 4 presents a morphological map that demonstrates in a general way how a threat evolves from some initiating event to some physical outcome. In Figure 4 the threats mapped do not extend beyond initial outcomes; thus subsequent outcomes such as bioconcentration and spread of poisoning via vector or the food chain are not included. Although the map presented in Figure 4 is not fully detailed, it can be seen that there are numerous ways in which threats could develop. Thus for practical purposes it will be necessary to limit the number of threats that are considered.

Common Threats in Hazardous Waste Management

Table 5 identifies some of the more important categories of threat that may occur in hazardous waste management and indicates the waste management techniques that are likely to pose these threats. Threat mechanisms are more fully discussed in Appendix B, which also includes data on the probabilities of some initiating events.

ECONOMIC AND SOCIAL EFFECTS OF HAZARDOUS WASTE MANAGEMENT TECHNIQUES

Classification of Effects

Use of various hazardous waste management techniques results in economic and social effects. The effects may occur either as a direct result of the waste management techniques used, or they may occur via environmental impacts. For hazardous wastes, many environmental impacts will take the form of threats as opposed to readily predictable impacts. Analysis of waste management problems usually identifies two major categories of economic and social effects--control costs and damages. This is consistent with the cost-benefit approach to pollution control discussed earlier. Though actual benefits (as opposed to damages averted) may sometimes arise from the use of waste management techniques (as with resource recovery), these can be accounted for by credits against control costs.

The term "damage costs" has been replaced by "environmental costs" and "social impacts" for two reasons. First, the term "damage costs" does not take account of differing viewpoints. If, for example, a waste management scheme involves the construction of a dam on a river, moving water recreationists (e.g., kayakers) will perceive this as a damaging effect, but still water recreationists (e.g., water-skiers) will perceive it as a benefit. Second, although most authorities agree that it is conceptually possible to attribute a dollar value to any effect (see Appendix C), the practical difficulties can be overwhelming (Organisation for Economic Co-operation and Development, 1974). Hence some effects may be more appropriately described than given a dollar value.

In this report, the term "environmental costs" is used to describe the direct results of the environmental threats already discussed, translated as

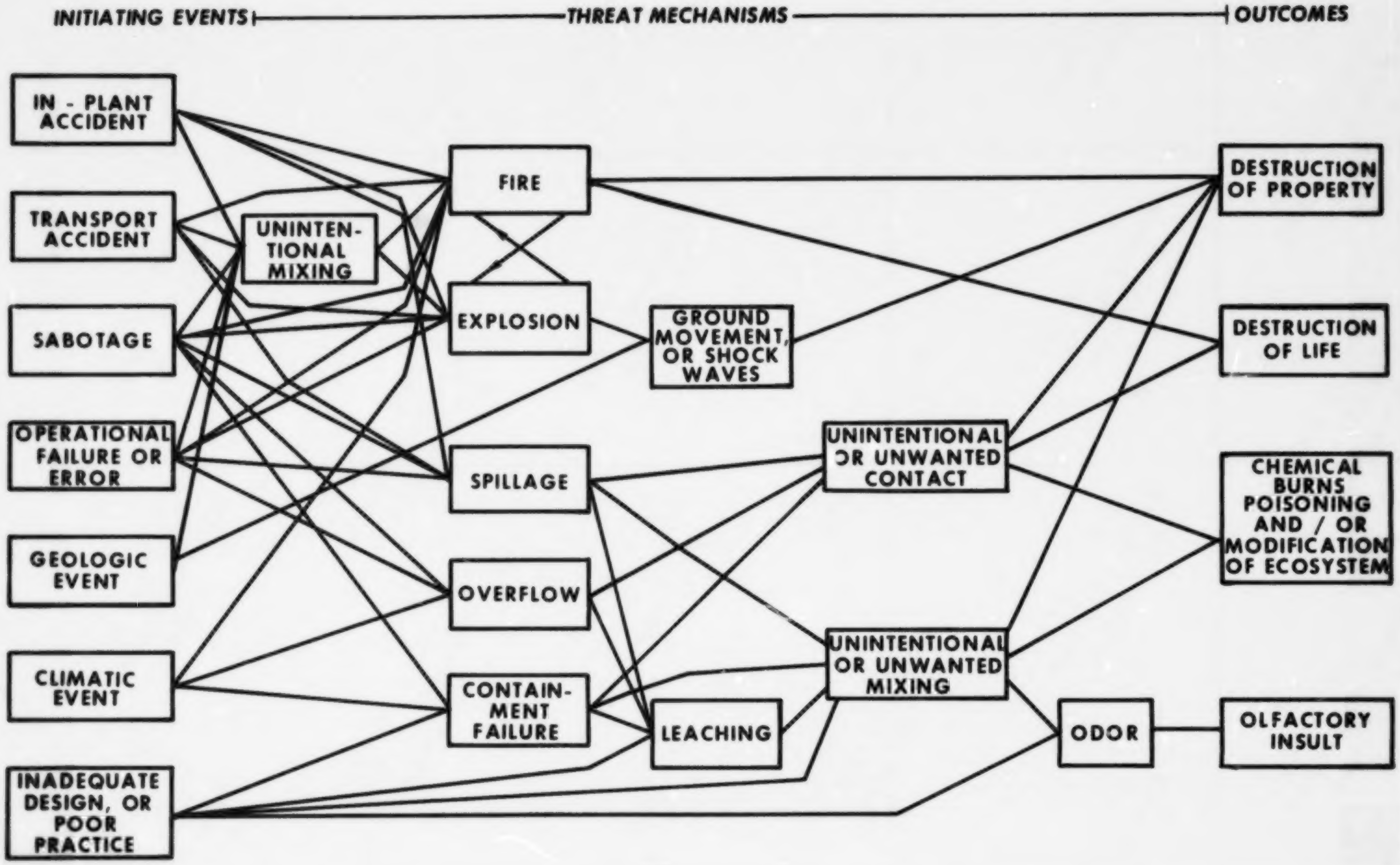
INITIATING EVENTS
THREAT MECHANISMS
OUTCOMES
IN - PLANT ACCIDENT
TRANSPORT ACCIDENT
SABOTAGE
OPERATIONAL FAILURE OR ERROR
GEOLOGIC EVENT
CLIMATIC EVENT
INADEQUATE DESIGN, OR POOR PRACTICE
UNINTEN-TIONAL MIXING
FIRE
EXPLOSION
SPILLAGE
OVERFLOW
CONTAIN-MENT FAILURE
GROUND MOVEMENT, OR SHOCK WAVES
LEACHING
UNINTENTIONAL OR UNWANTED CONTACT
UNINTENTIONAL OR UNWANTED MIXING
ODOR
DESTRUCTION OF PROPERTY
DESTRUCTION OF LIFE
CHEMICAL BURNS POISONING AND / OR MODIFICATION OF ECOSYSTEM
OLFACTORY INSULT

Figure 4. Morphological map of environmental threats.

TABLE 5. MAJOR THREATS THAT MAY OCCUR IN HAZARDOUS WASTE MANAGEMENT

Threat category	Hazardous waste management technique to which threat may apply
1. In-plant accident (spill, fire, explosion) leading to acute poisoning, destruction of property, etc.	All
2. Systematic in-plant exposure resulting in chronic poisoning of workers	All
3. Waste handling accident (spill, fire, explosion) during waste collection or disposal operations, leading to acute poisoning, destruction of property, etc.	All
4. Transportation accident leading to acute poisoning, destruction of property, water pollution, etc.	Wherever waste is transported from site of generation
5. Failure of treatment process resulting in waste that retains hazardous properties or acquires new hazardous attributes	Any treatment process
6. Groundwater contamination via leachate	Lagooning, land application, landfilling, mine disposal, possibly engineered storage
7. Surface or groundwater contamination by failure of containment	Lagooning, landfilling, mine disposal, engineered storage
8. Surface water contamination via runoff or indirectly from seepage of polluted groundwater	Lagooning, land application, landfilling
9. Modification of marine ecosystem by presence of waste	Ocean dumping
10. Direct groundwater contamination by presence of waste	Deep well injection

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far as practicable into economic terms. "Social impacts" is used to describe all remaining effects, including those that are essentially psychological. Thus in general, environmental costs arise from the threat of physical environmental degradation leading to some specific potential economic loss. Social impacts, on the other hand, need not involve any physical damage, are more likely to involve differing viewpoints, and will more frequently defy quantification in dollar terms. This terminology was chosen for convenience and may not coincide with that used by other sources. Furthermore, in some cases, allocation to an environmental cost or a social impact may be arbitrary. Nevertheless, maintaining this division may help to ensure that all possible effects are considered.

Exclusion of Secondary Effects

This study does not generally address secondary effects, which in the economic context are multiplier effects that reflect the fact that one person's expenditures constitute another's income. Secondary benefits are usually disregarded in cost-benefit and cost-effectiveness analysis because under conditions of full employment of resources, the resources used in secondary activities would be employed elsewhere in equivalently productive activities (Herfindahl and Kneese, 1974). Clearly, this argument is not always valid. Regional economists who are faced with a contracting economy and immobile factors of production (or conversely with a boom-town situation and shortages) may be vitally interested in economic multiplier effects; and such effects could be important in some hazardous waste management decisions. However, the author supports the view expressed by Maass (1966) that only where secondary effects (such as income redistribution) are made a part of project objectives (and thereby cease to be secondary), should they be included in evaluations. Hence in this analysis the costs considered are restricted to those conventionally used in assessing economic efficiency, except that environmental externalities (sometimes called "spillovers") will, of course, be included.

Types of Control Costs

Control costs associated with any approach to hazardous waste management may include the following:

1. Generator's costs, or those incurred by the firm that generates or may generate the hazardous waste. These include the costs of treatment, transport, and disposal of the waste, which may be performed by the firm itself or by its contractors. They also include the generator's relevant administrative, legal, and research and development costs.

2. Administrative costs, or administrative and enforcement costs incurred by governments or by any other body that oversees or monitors hazardous waste management.

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3. **Social control costs**, or costs that reflect the differences between the dollar costs actually incurred by the waste generator for various services, and the true cost to society of these services. Such costs might arise, for example, where a government provides a waste disposal facility free or at a subsidized charge. (These costs do not include an accounting of external environmental costs, which are covered elsewhere.)

In general, all control costs can quite readily be expressed in dollar terms, although for some there can be problems in deciding on the most appropriate method of valuation. For example, should a landfill site be valued at historic cost, at replacement cost, or at opportunity cost with the land used for another purpose? If the latter, what use (e.g., farming or housing) should be the basis of valuation? Control costs are discussed in more detail in Appendix C.

Types of Environmental Costs and Social Impacts

Several sources provide broad discussions of the evaluation of environmental damage, including both environmental costs and social impacts as defined in this study (Mäler and Wyzga, 1976; Organisation for Economic Cooperation and Development, 1974; Saunders, 1976; Bishop and Cicchetti, 1975). In general, empirical studies that involve pervasive pollutants (air pollution and radiation) appear to be the most advanced, possibly because the sources and receptors are comparatively easy to identify. During this research, no studies were found that addressed the empirical valuation of damages associated with solid or liquid hazardous wastes in a cost-benefit or risk-benefit framework, and only one was found that did so for hazardous emissions to air (Moll et al., 1975). Talley and Albrecht (1974) have made a preliminary analysis of the economics of hazardous waste control in which the emphasis was theoretical, and at the other end of the scale, individual waste-related damage incidents have been investigated (see Appendix B). Although a systematic analysis of the various environmental and social impacts of hazardous waste control techniques has not been made, the types of damage that may occur and many of the effects are common to other aspects of environmental and cost-benefit analyses. Hence methods of valuation may be derived from these sources.

The environmental impacts that most frequently arise from the use of hazardous waste management techniques can conveniently be divided into five categories for valuation purposes:

1. Destruction of, or damage to man-made structures;

2. Damage to human life and health;

3. Destruction of, or damage to animals, vegetation and land ecosystems, and kills of fish and other aquatic life in surface waters (including the impacts of ocean dumping);

4. Changes in property values;

5. Aesthetic factors and option values.

The first three categories (which mainly lead to environmental costs) relate to the physical impacts that can arise from the threat mechanisms. An additional physical impact, the modification of climate, can arise from many sources (Saunders, 1976), but is unlikely to be significant in hazardous waste management.

Changes in property values may reflect actual damages (usually noise or air pollution), or they may be essentially psychological in origin, reflecting aesthetic factors. Thus changes in property values can constitute environmental costs and/or social impacts, as defined here.

The final category is intended to cover all remaining social impacts (i.e., those that do not involve direct economic costs). It includes the aesthetic value of the environment, the existence value that stems from the knowledge that something exists or is being conserved, and option values associated with risk aversion and uncertainty.

Note that a single environmental impact can give rise to more than one of the above categories of effect. For example, persistent pollution of a river could cause fish kills, changes in adjacent property values, and a reduction in the aesthetic appeal of the river to bystanders. Thus the distinctions drawn above among the five categories of effects stem largely from the methods, described in Appendix C, that can be used for valuation. Since there can be overlaps between the categories (e.g., between damage to property, property value, and aesthetic value) care must be taken to avoid double counting when evaluating costs and impacts.

THE PARTIES-AT-INTEREST IN HAZARDOUS WASTE MANAGEMENT

The Concept of Parties-at-Interest

In analyzing the effects of using a hazardous waste management technique or an approach to hazardous waste control, the viewpoint of man is of ultimate concern; i.e., What effects does the use of a given approach or technique have on mankind? As has been shown, these effects can range from those that are direct and straightforward, such as dollar costs actually incurred in waste disposal, to those that are highly indirect, as for example the value that many individuals place on the preservation of a natural undisturbed ecosystem, which causes them to associate a cost with the modification of that system by the introduction of waste materials. Correspondingly, the distribution of these effects can vary from those that affect a single firm to those that impinge upon the general public.

This research is oriented toward the needs of decisionmakers who may have multiple criteria, including social and political goals, for the acceptability of a hazardous waste management plan. Hence in this study, recognition of different viewpoints and a means of taking account of social interactions is desirable. This can be achieved by grouping individuals into

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parties-at-interest. Each party-at-interest constitutes a class or group of individuals or enterprises that can reasonably be expected to have a common interest and viewpoint on the outcome of any particular plan or policy alternative (Gilmore et al., 1971; also see Royston and Perkowski, 1975).

For manageability, the parties-at-interest must be limited to those that are quite strongly affected by one or more of the alternatives being evaluated. Clearly, the grouping of numerous individual viewpoints and attitudes into a limited number of parties-at-interest constitutes something of a blunt instrument. However, it does permit the sociological aspects of alternative plans or policies to be considered, and by being able to observe the distribution of effects among different parties-at-interest, it provides a useful foundation for considering equity.

Identification of Parties-at-Interest in Hazardous Waste Management

The parties-at-interest in hazardous waste management may be determined from the effects that might arise from the use of the various control techniques. These effects fall into two general categories: Effects (such as control costs) that arise directly from the use of a hazardous waste management technique, and effects that arise via environmental impacts. Note that an environmental impact need not actually occur to be real from the viewpoint of the analysis. Both very unlikely threats and completely imaginary effects may be of importance. For example, residents near a proposed landfill may fear that their property values would be depressed by the proximity of the landfill. Even if this fear ultimately proves to be incorrect, it is a real fear to the residents, who will therefore respond to it in some way, and hence it is an effect to be considered.

Some economic effects, and hence parties-at-interest, arise indirectly. For example, in considering the effects of using different hazardous waste management techniques within a given industry, all the firms that use a particular hazardous waste generating process could constitute one party-at-interest; firms using another process that does not generate a hazardous waste could constitute a different party-at-interest. In this case, the effect would occur through changes in the competitive situation within the industry reflecting different hazardous waste disposal costs to the firms, and leading to changes in production costs.

The parties-at-interest in a given hazardous waste management situation may be deduced by examining the effects of every technique that might be used to manage the wastes (including no change from present practice). Political officials and administrators in environmentally oriented government agencies are also included, as they will want to minimize dissension among their constituencies and facilitate effective administration.

Examination of the approaches that can be used to place a value on the effects (Appendix C) may be helpful in identifying parties-at-interest. Gilmore et al. (1971) list four groups of parties-at-interest, as follows:

1. Parties internal to the affected industry (e.g. owners, stockholders, management, employees and their unions);

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2. Suppliers and customers of an affected industry (e.g., vendors of materials and services, including financing, insurance, and intermediate and final consumers);

3. Government (at different levels and in different roles, including legislators, executors, adjudicators, taxers, regulators, and those concerned with economic stability, social welfare, and national security);

4. Affected bystanders (e.g., those concerned with resources, wildlife, recreation potential, and aesthetic effects, and investors, employees, residents, and other property owners).

Gilmore et al. included parties-at-interest associated with secondary economic effects (suppliers and customers of an affected industry). As already indicated, the methodology proposed in this study follows the commonly accepted approach of not evaluating secondary effects. However, in cases where secondary economic effects are particularly significant, these could lead to some important parties-at-interest. Consideration of these parties-at-interest may help in understanding the sociology of the situation, even if the associated secondary economic effects are not directly included in any cost-benefit calculations.

Costs and Parties-at-Interest for Hazardous Waste Management Techniques

Table 6 summarizes the most important environmental threats, costs (and impacts), and parties-at-interest associated with hazardous waste management techniques. In specific situations, additional threats, costs and parties-at-interest may be important. Table 6 also includes disposal to the sewer and to surface waterways. Though these would not normally be options legally available to the hazardous waste generator, they are of interest since they might be used illicitly or for wastes that unexpectedly remained hazardous after some form of treatment.

Certain costs and parties-at-interest are present for every available technique. For example, the firms generating the waste will always have some disposal costs, and their managers and workers will always be parties-at-interest. This does not imply that the costs or the posture of the firm will be the same for each technique. Similarly, it can be assumed that local government and environmental agencies will be interested in every technique that might be used. The term "local," in this context, means having jurisdiction over the location at which the technique is employed, hence different local officials may be parties-at-interest to different techniques. Similar considerations apply every time the term "local" is used (e.g., local residents, local property owners, etc.). These parties-at-interest are the individuals that are close enough to the location of the technique under consideration to potentially be affected by it.

The potential for freshwater contamination occurs with many of the techniques, giving rise to associated costs. Where water contamination costs are listed in Table 6, these costs can include the contamination of water supplies (from surface or groundwater sources) for human or agricultural use,

TABLE 6 ENVIRONMENTAL THREATS, COSTS, AND PARTIES-AT-INTEREST FOR HAZARDOUS WASTE MANAGEMENT TECHNIQUES

Technique	Environmental threats	Parties-at-interest	Major costs, etc.	Comments
All techniques	Surreptitious dumping or accidental discharge to land, sewer, or waterway In-plant accidents involving fire or explosion Acute and chronic poisoning	Waste generators-management, Waste generators-workers, Competing firms using different process, Waste disposal industry, Local political officials, Local environmental officials, Water supply authorities, Environmentalists	Capital and operating costs for waste disposal (internal costs to generator)	
All techniques involving offsite activities	Surreptitious dumping Accidental spillage (to land or water)	Waste transporters, Residents along transport corridors	Transport cost	
Change in waste streams*		Secondary materials industry		May facilitate resource recovery
Resource recovery		Secondary materials industry, Virgin materials suppliers		Resource recovery may have adverse effect on energy usage
Treatment to reduce hazard	Treatment may fail leaving waste still hazardous (most likely with biological treatment)	Fishermen (where effluent is discharged)	Additional capital and operating costs for necessary processes, less value of any resources recovered	
-Physical				Increased energy usage likely
-Chemical		Chemical suppliers		
-Biological				
-Thermal	Air pollution	Local residents/workers Local property owners		Possibility of energy recovery
-Encapsulation				
Land application	Crop take-up of toxic elements Soil sterilization Leaching/run-off Odor	Farmers Local water supply users Residents/workers/property owners adjacent to land Fishermen	Aesthetics Poisoning via food chain Water contamination	Any nutrients, etc., present may enhance crop growth

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* The threats, parties-at-interest and costs identified from this point on are in addition to those listed above.

(continued)

TABLE 6 (Continued)

Technique	Environmental threats	Parties-at-interest	Major costs, etc.	Comments
Landfilling	Leaching/run-off Odor Vectors?	Local water supply users Local residents/workers/property owners Fishermen	Water contamination Aesthetics	Need to consider opportunity cost of land
Mine disposal	Leakage to groundwater	Holders of adjacent mineral rights	Groundwater contamination	Need to consider opportunity cost of mine
Lagooning (for storage or evaporation)	Leaching Overflow Odor and air pollution	Residents/workers/property owners adjacent to site Local water supply users Fowl hunters Farmers?	Water contamination Aesthetics	Need to consider opportunity cost of land
Deep well injection	Groundwater contamination Land movement and consequent property damage	Authorities concerned with resource usage Local residents/property owners Scientists	Groundwater contamination Property damage	There may be an opportunity cost to using the aquifer
Ocean dumping	Modification of marine ecosystem	Ocean fishermen Ocean recreationalists Coastal recreation-related industry Local residents/workers/property owners Scientists Other nations, national politicians	Reduced or inedible fish catch Reduced tourist income Aesthetics Possible international political strife	
Engineered storage	Containment failure	Local residents Local water supply users?	Maintenance after disposal is completed Water contamination	Requires perpetual monitoring and maintenance
Space disposal	Contamination of space Launch failure consequences	Scientists Other nations, national politicians	International political strife Unknown scientific costs	
Discharge to sewer	Waste may destroy biological treatment colonies Waste may cause sewage sludge to become hazardous Slugs of waste may overload system	Sewer authorities	Malfunction of sewage works and consequent damage	These two actions are not normally legitimate hazardous waste management techniques, but are included here because a treatment process may fail resulting in a hazardous effluent; or they may be used covertly
Discharge to waterway	Waste may destroy aquatic life	Fishermen Other water users Local recreation-related industry Residents/workers/property owners adjacent to waterway Local water supply users? Scientists?	Aesthetics Reduced recreational opportunities	

and the pollution of other surface waters. The cost involved in the first case can include installing replacement sources of drinking and agricultural water, corrosion and materials damage costs (to pipes and appliances), foregoing the use of water or continuing to use the contaminated water and accepting lower crop yields and values (for agricultural irrigation), and aesthetic costs. (Persons who use their own well water may consider it aesthetically more satisfying than piped water, and hence suffer an aesthetic cost if they are forced to obtain water from public systems.) The costs associated with the pollution of surface sources not used for water supply can include fish kills, devalued recreational opportunities, environmental aesthetic costs, and loss of future options.

Cleanup or mitigation costs could be involved where there is any form of contamination. These costs can be particularly expensive for groundwater sources which cannot feasibly be treated after withdrawal. In this event, normal procedure is to counterpump wells drilled to intersect the plume of contaminated water, and then to dispose of this water. Even this procedure is not always entirely successful (U.S. Environmental Protection Agency, 1977c; Miller, 1974).

THE SOCIOECONOMIC INTERACTION PROCESS

The Interaction Model

This section presents a simple conceptual model of the interactions between the technical (i.e., physical) aspects and the economic and social aspects of hazardous waste management. The purpose of the model is to enhance understanding of the relationships between hazardous waste management policy, what physically happens to the wastes, and the effects that this has on society. The model forms the basis of the evaluation procedure described in Section 5, and is inevitably a compromise between the desire for simplicity in analysis, and the complexities that may be encountered in real-life situations.

The model is illustrated in Figure 5. It is divided into three sections, or levels: The policy level, the technical level, and the socioeconomic level. The policy level is concerned with the philosophy of how hazardous wastes are to be managed. Decisions at the policy level are largely responsible for determining what goes on at the technical level, which deals with what physically happens to the wastes and to the environment. In turn, actions at the technical level have effects at the socioeconomic level (i.e., on society). There is feedback from the socioeconomic level to the policy level through the technical level.

The elements in the model and the linkages between the elements are briefly described below. Most of these elements are discussed in more detail elsewhere.

Policy Objectives--

Policy objectives, dealing with normative (judgmental) issues, are considered to be an exogenous input to the model (see Section 5).

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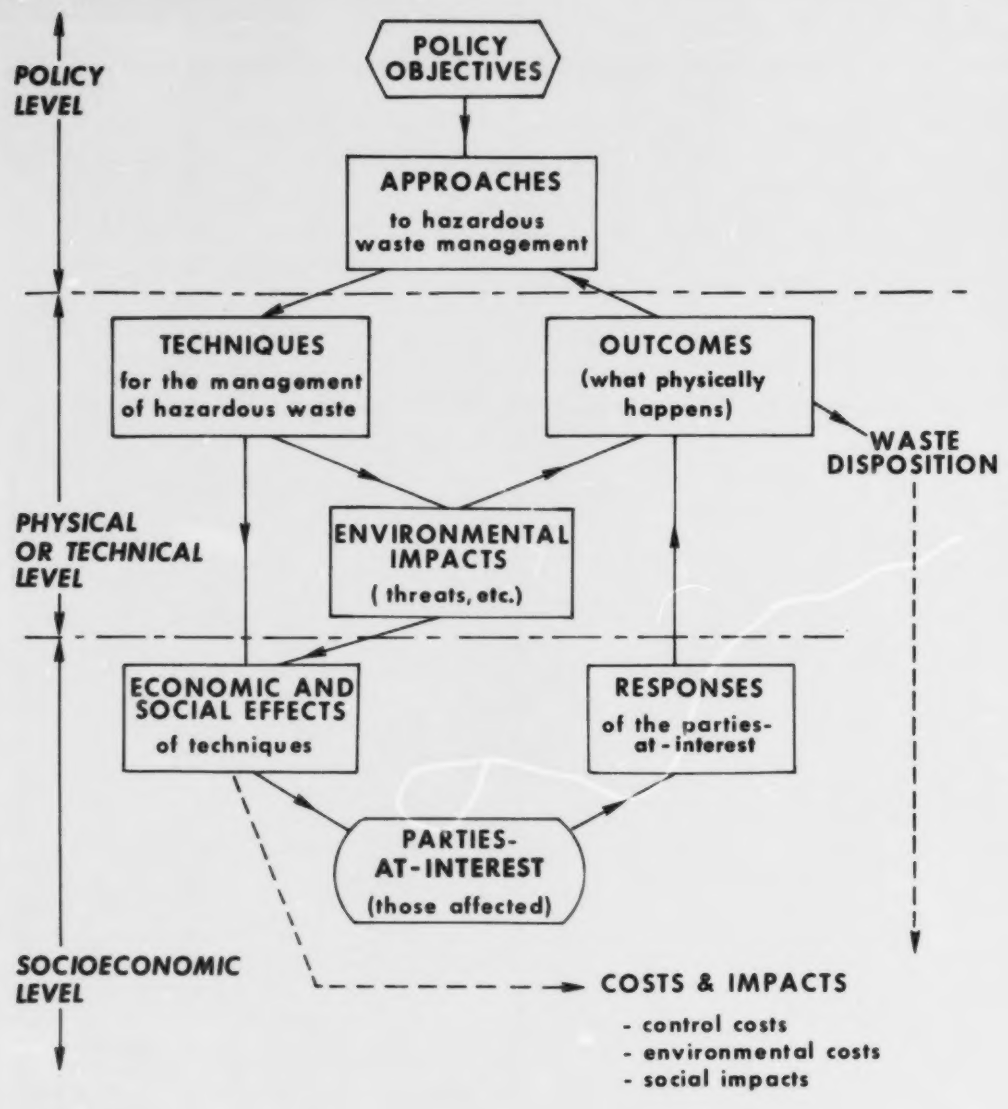
POLICY LEVEL
POLICY OBJECTIVES
APPROACHES to hazardous waste management
TECHNIQUES for the management of hazardous waste
OUTCOMES (what physically happens)
WASTE DISPOSITION
PHYSICAL OR TECHNICAL LEVEL
ENVIRONMENTAL IMPACTS (threats, etc.)
ECONOMIC AND SOCIAL EFFECTS of techniques
RESPONSES of the parties-at-interest
PARTIES-AT-INTEREST (those affected)
SOCIOECONOMIC LEVEL
COSTS & IMPACTS
- control costs
- environmental costs
- social impacts

Figure 5. Interaction model for hazardous waste management.

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Approaches to Hazardous Waste Management--

The approaches to hazardous waste management represent strategies for the control of hazardous waste that are consistent with the policy objectives. Approaches may favor the use of certain techniques (see Section 5).

Techniques for the Control of Hazardous Waste--

Techniques are the physical methods (e.g., treatment, landfilling) that may be used to manage or control hazardous waste (see Section 3 and Appendix A). They may include environmentally unacceptable techniques, such as surreptitious dumping. The use of a given technique results directly in control costs (one of the economic and social effects) and also causes or has the potential to cause environmental impacts.

Environmental Impacts--

Environmental impacts are the physical effects, or potential effects, that could arise from the use of various hazardous waste management techniques. They occur largely in the form of threats (discussed early in this section and in Appendix B). In addition, pervasive effects that relate to resource use may be of interest. Thus although the economic aspects of energy or materials consumption attributable to the use of a technique are accounted for within the control costs (including any credits for resource recovery), these topics may be of specific interest and call for individual treatment. The same argument applies to land use, which is another aspect of resource use. Note that if the emphasis is on conservation of resources, some base case will be needed for comparison.

Economic and Social Effects of the Technique--

The economic and social effects are the effects that the techniques have on man. These effects give rise to costs and impacts (i.e., control costs, environmental costs, and social impacts, discussed earlier in this section). In addition, man may have a special interest in certain aspects of resource use, as discussed above.

The Parties-at-Interest--

The economic and social effects will affect different groups of individuals or enterprises in different ways. Each group that is relatively homogeneous in terms of its interests and attitudes and in the way that it is affected by the economic and social effects of the techniques constitutes a party-at-interest (as discussed earlier in this section).

Responses of the Parties-at-Interest--

The various parties-at-interest will respond to the economic and social effects in ways that will be determined by their interests and attitudes. Their responses could include opposing or supporting a scheme or policy, choosing a waste disposal technique, changing business activities, moving to another location to avoid an adverse effect, etc. (Responses are discussed later in this section.)

Outcomes--

The outcomes represent what physically happens in terms of hazardous waste management, allowing for all the interactions and linkages that exist in practice. Thus prediction of outcomes involves determining what is likely

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to happen to the various hazardous wastes, i.e., how much will be disposed of by each technique, and the extent to which waste generation will change as the result of using any particular approach to hazardous waste management. The outcomes also include the environmental effects that occur or are threatened.

There is feedback from the outcomes to the approaches to hazardous waste management. When a decisionmaker predicts or observes the outcomes that result from a given approach to hazardous waste management, he may wish to modify that approach to change the outcomes and the associated economic costs and social impacts. (Outcomes and the complete interaction process are discussed in Section 5.)

Attitudes Toward Hazardous Wastes and Their Management

To be able to predict responses of the parties-at-interest and hence to determine likely outcomes of approaches to hazardous waste management, it would be desirable to know something about the attitudes that individuals have toward hazardous wastes and the environment.

Only one study has specifically addressed public attitudes toward hazardous waste management facilities. This extensive study surveyed both a random sample and selected influential respondents (e.g., newspaper editors) in 10 U.S. counties that were considered feasible locations for national disposal sites (Lackey, Jacobs, and Stewart, 1973). The study reported generally favorable attitudes toward the national disposal site concept and location of such a site in all counties surveyed. These favorable attitudes appeared to relate to the beliefs that a disposal site would conserve material resources and result in a strong local economy (i.e., provide employment) (Lackey, Jacobs, and Stewart, 1973). However, during the testing of the questionnaire, it was found that the term "disposal" had negative connotations for the respondents, and accordingly national disposal sites were described as "regional processing facilities" in the survey instrument (Lackey, Jacobs, and Stewart, 1973). This situation does raise the question as to whether or not the respondents really understood what they were being asked. If not, the attitudes reported by Lackey, Jacobs, and Stewart might change when the issue becomes clearer.

It was initially hoped that a study of attitudes toward nuclear power (and nuclear wastes) and toward hazardous waste generating industries (such as the chemical industry) would provide useful information on attitudes toward hazardous wastes. The intention was to use the chemical industry as a proxy for a hazardous waste management facility and to draw parallels between nuclear power, with its radioactive waste disposal problem, and nonradioactive hazardous waste disposal. Other than for nuclear power, little relevant material on attitudes toward waste generating industries was found during this research.

Though there have been many attitudinal studies relating to nuclear power (several of which have included the question of nuclear wastes), it was concluded that attitudes toward nuclear power would be of very limited value in predicting attitudes toward nonradioactive hazardous wastes and their management. This is because several studies have suggested that the public associates the possible discharge of radioactivity from nuclear power plants and wastes with the effect of nuclear weapons (Pahner, 1976; Louis Harris and Associates, Inc., 1976; Rappeport and Labaw, 1975; Slovic and Fischhoff, in press). Though hazardous wastes comprising obsolete chemical warfare and ordnance materials could to some extent pose an analogous type of threat, in general, reactions to nuclear facilities appear too extreme to be appropriate for nonnuclear hazardous wastes. However, one finding about nuclear power plants may be applicable to some hazardous waste management facilities: Familiarity can evidently breed acceptance. Those living near a nuclear reactor perceived it as safer than those living farther away (Maderthaner et al., 1976; also see Klein, 1978). (However, it is possible that this finding may reflect an element of self selection, with those who are concerned about the risks tending to move away from nuclear power plant sites.)

As a result of the paucity of data that could provide specific guidance on attitudes toward hazardous wastes, a broad survey of research on attitudes to the environment was undertaken. This survey provided some general guidance on the attitudes and priorities of the general public and some special interest groups (i.e., parties-at-interest) toward pollution problems, and it is summarized in Appendix D. Based on these findings, the EPA-sponsored meetings on hazardous waste management (see Corson, 1976; U.S. Environmental Protection Agency, 1976c; Edelman et al., 1976), and the material discussed above, the following list presents some generalizations about the likely attitudes and behavior of various parties-at-interest.

1. Firms desire to minimize their internal costs, including management costs.

2. Wastes are a nuisance to manufacturing firms, which in most cases will not devote much effort to their disposal unless disposal represents a significant cost to them, or unless there is a significant risk of public opposition to the firm or its products because of its waste disposal practices.

3. In selecting a waste disposal technique, firms will tend to favor those that enable them to dispose of the responsibility for the waste along with the waste.

4. Large firms are the most likely to be environmentally responsible, as they have high public visibility. Smaller firms are more variable in their concern for the environment.

5. Workers are concerned with their own physical safety and with security of employment. Often, however, the latter outweighs the former in determining their actions.

6. Local government and environmental officials prefer to adopt policies that minimize the risk of adverse incidents (i.e., they are strongly risk averse).

7. Wastes are politically negative, and local politicians prefer them to go elsewhere.

8. Residents are concerned with property values. They fear that nearby waste processing or disposal sites will depress property values.

9. Residents are generally uneasy about wastes. They often object strenuously to wastes from another jurisdiction, especially another State.

10. Residents have some interest in local employment, tax base, etc.; but the strength of this interest tends to depend on the employment history in the area. Local politicians and businessmen often have strong interests in these areas.

11. Environmentalists wish to minimize all environmental risks and tend to resist change, with only limited concern for costs.

12. Environmentalists exhibit high existence values (see Appendix C), and may claim that no compensation would be great enough to justify some adverse environmental impacts.

13. The public has become cautious about new technologies, especially those that they do not understand. Established technologies are more acceptable (hence, the chemical industry is less threatening than nuclear power). Public credulity toward scientific expertise is declining.

14. In some cases, those close to a facility that is perceived to be hazardous are less concerned about it than those that are somewhat farther away.

15. The public favors conservation and recycling. Most (but not all) accept the need to dispose of some wastes. However, few individuals are prepared to go to great lengths to promote their ideals.

Responses of the Parties-at-Interest

The responses of the parties-at-interest are very closely related to the economic and social effects that arise from the use of the various hazardous waste control techniques. Although human behavior is not always predictable, it may be possible and useful to identify likely responses of the parties-at-interest to the various economic and social effects that they experience. The views expressed in this section are based on the material discussed above, the author's experiences with manufacturing industries, and from discussions with individuals who are involved with hazardous waste management in the western and northwestern United States.

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Responses to Positive Effects--

Many of the impacts that would be regarded as positive (i.e., beneficial) by the parties-at-interest are comparatively weak and are unlikely to elicit an active response. For example, assume that it is proposed that one class of firm be required to use a costly process to dispose of its hazardous waste (a strong negative impact on these generators). Competing firms that use a different process that does not generate hazardous waste will perceive a mild positive impact (since the competitive situation will be changed in their favor). However, these competing firms are likely to be passive in taking advantage of this situation and probably would not publicly support the proposal, partly out of fear that they might be next to be so regulated. On the other hand, the hazardous waste generators are likely to protest the proposal (on the grounds that it will weaken their competitive position) and probably will exert whatever pressure that they can to get it modified. This type of behavior was recently demonstrated in the U.S. steel industry. Several plants had difficulty in meeting air and water effluent standards and asked that variances be permitted on the grounds of economic hardship. On the other hand, firms whose plants had little difficulty in meeting these standards remained comparatively quiet on the subject.

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Perhaps the only category of positive impact that is likely to trigger a strong response is that of an impact on an environmentalist. Environmentalists tend to support actions that they perceive as positive by interaction at public meetings and through the political process.

Responses to Changes in Generator's Costs--

Any change in generator's costs for hazardous waste disposal must either be absorbed by the firm or reflected in product prices, or both. If the change is an increase, internal absorption will reduce the firm's earnings and weaken its position in the capital market to the ultimate detriment of the shareholders; whereas an increase in product price will reduce unit sales, depending on the price elasticity of demand. If the long-run elasticity is known and the firm is assumed to be a profit maximizer, it is theoretically possible to determine the extent to which the firm can pass a cost increase on to its customers. However, some manufacturing firms (primarily those that make nondifferentiated products) have little control over the prices that they receive for their products, and even where this is not the case, pricing decisions are not always made on the basis of maximizing profit (Kotler, 1967; Backman, 1965). Indeed, some marketing authorities claim that manufacturing costs are one of the last factors considered when selecting a consumer product price (Oxenfeldt, 1960). Hence, prediction of a firm's response to a change in costs may not be an easy matter.

Fortunately, it appears that the costs of adequate hazardous waste management are often a small proportion (about 1 percent) of the value of shipments (U.S. Environmental Protection Agency, 1974b). Hence in many cases, it may be possible to neglect the effect, even though small changes probably have an effect on pricing in the long run. Where changes in hazardous waste management costs could represent a significant proportion of the product price, an examination of the pricing structure of the revelant industry would be desirable to establish likely behavior.

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Response to Negative Impacts--

The category of impact that appears to be the most likely to evoke an active response is that of a negative impact via an environmental threat. Responses are likely to include local opposition to the siting and operation of most hazardous waste management facilities, but avoidance actions (e.g., moving to another house) are only likely when the threats become realities. Nizard and Tournon (1974) have developed a simple model (Figure 6) that predicts the circumstances under which an individual will tolerate pollution and those under which he will be predisposed to respond against it. Local residents, etc. frequently object to chemical landfills. This can extend to lagoons and some hazardous waste storage facilities (see Appendix C). Under some circumstances resource recovery facilities could benefit from the positive connotations associated with the concept of resource recovery, but this could easily be degraded by negative experiences. Alternatively, a resource recovery operation might merely be regarded as a regular manufacturing plant.

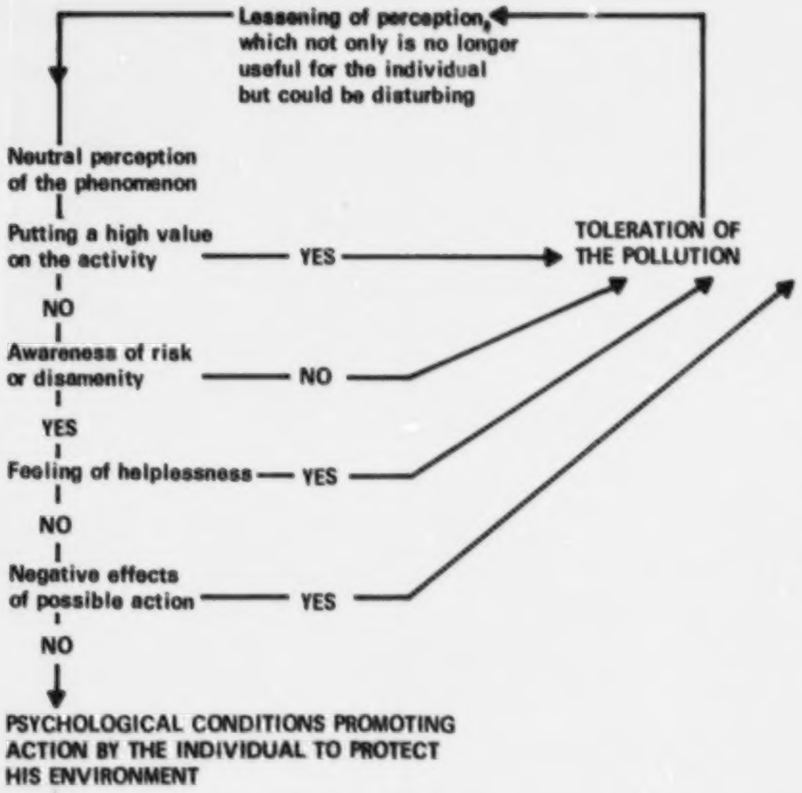
Lessening of perception, which not only is no longer useful for the individual but could be disturbing
Neutral perception of the phenomenon
Putting a high value on the activity
YES
TOLERATION OF THE POLLUTION
NO
Awareness of risk or disamenity
NO
YES
Feeling of helplessness
YES
NO
Negative effects of possible action
YES
NO
PSYCHOLOGICAL CONDITIONS PROMOTING ACTION BY THE INDIVIDUAL TO PROTECT HIS ENVIRONMENT

Figure 6. Model for pollution toleration.

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Environmentalists usually respond vigorously to perceived threats and are likely to be joined by other groups strongly affected by threats (e.g., fishermen, where there is a threat to surface water quality). In addition to political actions, these parties-at-interest may use the judicial process to delay or halt projects. Responses of local administrative officials, etc. are likely to be more subdued and could include such tactics as negation by delay. There have, however, been a number of recent moves by political officials to prevent the disposal of particularly threatening wastes (obsolete nerve gas and radioactive wastes, for example) within their jurisdictions and even to prevent the movement of such wastes across them.

Again, when and if the threats materialize, fishermen, tourists, etc. will avoid polluted areas, and even if there is no official pronouncement on the matter, the public may reduce their consumption of suspect fish and game. (Some pollutants such as phenols and certain heavy metals give fish a bad taste or smell [Cannon, 1974].)

SECTION 5

GENERAL METHODOLOGY FOR ANALYSIS OF HAZARDOUS WASTE MANAGEMENT ALTERNATIVES

This section outlines a methodology that may be used by a decisionmaker to evaluate the effects of alternative approaches to managing hazardous wastes. The methodology involves three phases, as follows:

1. Obtaining prerequisite information;
2. Applying the analytical framework;
3. Decisionmaking.

Before the procedures and techniques for conducting these three phases are described, this section explains the objectives and some of the philosophy behind the methodology, and it introduces some aspects of economic theory that may be relevant to the analysis.

INTRODUCTION

The primary objective of the methodology is to provide a framework for the analysis of hazardous waste problems that is based on economics and that is cognizant of social factors. The methodology is intended (1) to assist a decisionmaker to systematically examine the various alternative approaches to controlling hazardous wastes, (2) to determine the nature, and as far as possible, the magnitude of the various effects that can occur, and (3) to thereby make informed and balanced hazardous waste management decisions.

The methodology is referred to as a "framework for analysis" because it provides structure and methodology for analysis, but it does not attempt to determine an optimum solution. Choice between alternatives remains the prerogative of the decisionmaker, who can make his own trade-offs and introduce whatever degree of risk aversion he favors. Indeed, the concept of an optimum solution (in the mathematical sense) is of limited value in hazardous waste decisionmaking, since where there are both economic and social considerations, decisions are considered "normative," i.e., they involve value judgments. Such judgments are necessary because the various impacts fall upon different parties-at-interest, thereby introducing questions of equity. There is also the question of risk. Different persons will have various attitudes toward risk-taking and hence will require different benefits to offset a given risk. Though an optimum solution could be determined if rules for decisionmaking were specified, in this methodology, the decisionmaker is encouraged to develop his own criteria on a case-by-case basis. Another feature of this approach is that although it is possible to place dollar values on changes in environmental features, the available techniques and data do not generally permit these valuations to be made with much confidence, and hence once again, judgments are likely to be necessary.

Thus situations encountered in hazardous waste management call for a systematic analysis of the various possibilities in such a way as to provide a decisionmaker with information about the trade-offs between the various alternatives. The decisionmaker can then use his own norms or criteria, or those he believes are representative of agency policy, to select an approach that satisfies whatever policy objectives may exist. This methodology attempts to provide a decisionmaker with the information that is needed to make decisions of the type outlined above. Though it was developed as an aid to making decisions about the management of hazardous industrial wastes on a regional or local basis, it could quite readily be adapted to special categories of hazardous waste or to specific industries, possibly on a national basis.

The methodology is not appropriate to determining whether or not a particular substance should be manufactured or to what extent it should be used (e.g., the use of PCB's). The latter problem has been addressed by other studies (e.g., Kennedy et al., 1975; National Academy of Sciences, 1977; Moll et al., 1975). The distinction is that the cost-benefit or risk-benefit studies mentioned above examine the cradle-to-grave costs and benefits of using a particular material, whereas this study essentially addresses only the problem of dealing with hazardous wastes, once those wastes have been created.

THEORETICAL CONSIDERATIONS

Some concepts from economic theory are difficult to apply in practice or are subject to debate, but they provide useful insights for hazardous waste management decisionmakers, and for this reason are discussed here. These concepts are Pareto optimality and market failures, and the handling of intertemporal effects.

Pareto Optimality and Market Failures

The Pareto Criteria--

The concept of Pareto optimality constitutes the apogee of planning goals in welfare economics.* Although it is unrealistic to expect a real economic system to be Pareto optimal, the concept is worth examining, as it provides useful guidance for decisionmaking.

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* Welfare economics has been described as ". . . the theory of how and by what criteria economists and policy-makers make or ought to make their choices between alternative policies and between good and bad institutions" (Arrow and Scitovsky, 1969:1). Consequently, hazardous waste decisionmaking by public officials falls within its purview.

The basis of Pareto optimality is that a situation is optimal (or "efficient") when *no one can be made better off without at least one person being made worse off*. Herfindahl and Kneese provide a useful discussion of Pareto optimality and show that it implies the following:

1. Efficiency in production: It is impossible in an optimum to increase the production of one good without decreasing the production of at least one other good;

2. Efficiency in distribution: It is impossible in an optimum to redistribute the goods among the consumers, so that one consumer is better off while no other consumer is worse off;

3. Allocation of resources in accordance with consumer preferences. (Herfindahl and Kneese, 1974:41,42)

It can be shown that there is no unique Pareto optimum, as an optimum depends on the initial conditions (Herfindahl and Kneese, 1974). Since arrival at an *optimum* may be too much to expect in practice, projects can be examined for Pareto *improvements*, which occur if some economic change makes one or more persons better off without making any worse off (Mishan, 1971a).

Because of the difficulties inherent in arriving at a Pareto optimum or making a Pareto improvement within a real economic system, the concepts of a *potential Pareto optimum* and a *potential Pareto improvement* are often substituted as planning goals or tools. A situation is said to be potentially Pareto optimum if it can be transformed to Pareto optimality merely by making economic transfers between individuals--that is, that gainers be able to more than compensate losers (Mishan, 1971a). The acceptability of any given distribution of costs, benefits, income, etc. is considered separately, and this aspect is termed "equity" in this methodology.

The Problem of Market Failures--

It can be shown that perfect competition and its associated marginal cost pricing leads to Pareto optimal conditions. However, there may be circumstances in which major divergences from this situation occur, and these are termed "market failures." The failure that comes readily to mind is that of monopoly, as it is well known that where a monopoly exists, it is in the monopolist's interest to price goods at a level that is higher than the marginal cost of production. Thus where both monopoly and competition exist, to arrive at an *optimal* solution, it would be necessary to replace monopolistic prices by those based on marginal costs.

A particularly difficult problem arises where the monopoly is what is termed a "natural monopoly," in which long-run average costs decrease with increased output. In this case, the monopolist could not use marginal cost pricing unless he were given a subsidy, as the marginal cost would be below the average cost, and the monopoly would be incapable of recovering all its costs. This situation occurs where there are economies of scale over the entire range of output that is of potential interest. Many public services, such as sewage disposal and electricity supply, can be natural monopolies, and monopoly situations (both natural and otherwise) could well arise with some techniques for hazardous waste disposal. For example, high temperature incineration facilities suitable for hazardous waste might fall in this category, as they are comparatively capital intensive, and unless there were particularly large volumes of waste generated in one location, a high temperature incinerator would be likely to establish a monopoly within a zone of influence determined by transport costs.

Landfills constitute a rather interesting situation, because to some extent, their operation resembles the mining of a mineral deposit. Because of the finite capacity of a landfill, and because the land after filling is worth less than the land before filling, the variable costs should include an element of depletion to allow for the consumption of a resource (i.e., the space for disposal). Even so, there seems to be no reason why marginal costs should rise with the volume of waste handled for most chemical landfills. As a result, both their pricing and behavior are likely to reflect elements of monopoly. Since fixed costs (e.g., licensing, environmental monitoring, and security) can be comparatively high, marginal and average costs could differ significantly.

The second important area of market failure is where prices do not reflect externalities. Free use of environmental resources, such as the pollution assimilation capabilities of a river, provides a classic example of an externality (or "spillover effect," as it is sometimes called). If the waste generator does not pay for the use of the environment (which is a cost to society, since some individuals are damaged by a degraded environment), his production costs (known as his "internal costs") will be lower than the true costs, and consequently he will produce more of the good than is societally efficient (i.e., Pareto optimal). Furthermore, under these circumstances, there is no incentive for efficient use of the environment; since it is free to the generator, he will theoretically use whatever quantity it takes to minimize his unit production cost. (For a detailed analysis, see Barnett and Morse, 1963.) Since the environment generally has a limited restorative or treatment capacity, this can lead to a "commons situation" (Hardin, 1968), in which such capacity is overloaded because no individual user has sufficient incentive to reduce use.

A key part of the methodology described in this report is to identify and, if possible, evaluate such externalities. Furthermore, some approaches to hazardous waste management may involve the use of economic incentive means, such as user charges and effluent fees, that internalize these externalities. (Externalities can also be internalized by specific pollution control laws and the general laws of liability. See Anderson et al., 1977.) However, the question that is pertinent here is: What adjustments, if any, should be made to data where there are uncompensated market failures? There is some debate about the extent to which "shadow prices" should be used in cost-benefit analysis, where such prices are nonmarket prices--for example, prices based on marginal costs and benefits that fully reflect externalities (McKean, 1968). The differences between shadow and market prices will affect quantities of products and wastes produced (Freeman, Haveman, and Kneese, 1973). While shadow prices may be necessary to evaluate Pareto optimal conditions, the problem is that once one adjustment is made to one price, then output, consumption of other products, other prices, etc. will also change. In short, something of a chain reaction will be set off. Arriving at an optimum solution under these conditions is usually a complex task (Lipsey and Lancaster, 1956; Herfindahl and Kneese, 1974; Mishan, 1971a).

The analyst or decisionmaker has two interests when he identifies a market failure: First, what should he do if he has control over pricing, and second, how should he conduct his evaluations if he does not have that control? The pragmatic answer to the first question is that where he can control prices (through some policy means), it is probably more efficient to move towards marginal cost pricing, even though this is not employed in other sectors of the economy (see Price, 1977; Bohm, 1973). In the second case, the analyst should be cautious about substituting shadow prices for market prices in evaluations, unless the market failure is clearly a major one. The literature provides some support for this viewpoint (see McKean, 1968), and in addition a project is more likely to be accepted by the various parties concerned if the analysis is straightforward and readily comprehensible. Of course, external costs (such as environmental costs) should be included in the evaluation, which will partly correct the deviations from optimal conditions, and the analyst can also seek strategies that endeavor to eliminate market failures.

Ultimately, however, one should not lose sight of the fact that most analyses involve making changes from an existing situation. Provided that the new situation represents a potential Pareto improvement, society has gained and hence the analyst need not be too inhibited by the complexities of trying to find an optimum solution. (For more detailed treatments of these topics, see Mishan, 1971a,b; Scitovsky, 1951; Arrow and Scitovsky, 1969; Price, 1977; Bohm, 1973; Chase, 1968).

Intertemporal Considerations

It is very widely accepted that the discounted cash flow (DCF) approach is an appropriate technique for evaluating the economics of business projects where income and expenditures do not coincide in time. The approach is based on the concept that future income is less valuable than present income and, correspondingly, that future costs are less onerous than current costs, since in the intervening period the capital could be invested in some other way. Thus the discount rate chosen for any evaluation should be related to the opportunity cost of capital. This argument does not presuppose the existence of inflation, and is therefore applicable to costs and revenues expressed in constant dollars. In the event that under conditions of inflation with costs expressed in current dollars, the discount rate would need to be increased. (For further information on this topic, see Taylor, 1964; Merrett and Sykes, 1963; Stermole, 1974.)

The Social Discount Rate--

The basic concept of discounting can be applied to cost-benefit or cost-effectiveness studies of public investments but some difficulties can arise over the choice of an appropriate discount rate. There are two major aspects to these difficulties: (1) The question of the use of a social discount rate, which is lower than the business rate, and (2) whether or not the discount rate should be raised to reflect risk. Arguments for and against the use of a social discount rate are summarized in Appendix E. The key argument favoring the use of business discount rates is that if lower rates are used for public projects, capital will incorrectly be diverted from the private to the public sector, reducing overall economic efficiency. There are several countervailing arguments, but they all amount to the assertion that a low public discount rate is necessary to insure the appropriate mix of public and private sector projects. A business project that carries a strong risk of failure must usually offer a higher expected rate of return than one that is essentially risk free. However, when a project that involves risk or uncertainty is proposed for the public sector, there are some arguments against raising the discount rate to allow for risk.

Analysis of the literature suggests that the appropriateness of using a social discount rate depends on the nature of the project involved, and though arguments for using a risk-free discount rate predominate, there could be circumstances where a risk premium is appropriate for public projects. To a large extent, the solution depends on the degree of competition with the private sector. For example, evaluation of the perpetual care costs of storing long-lived wastes might use a low social discount rate, while evaluation of a project to install an incinerator as an alternative to a landfill might use a high-risk commercial rate, as this has the nature of a normal business decision.

Intergenerational Effects--

Up to this point, the discussion has been appropriate to actions and projects with a time span of a decade or two, since they revolve around decisions *from the viewpoint of the present generation*. However, where a longer time span is involved, the viewpoint of future generations should also be considered. This is particularly relevant for projects that result in *irreversible* changes--which may arise from any project that involves modification of the natural environment, the use or disposition of nonrenewable resources, or even construction.

When intergenerational effects are present, the arguments for the use of a low social discount rate become stronger, and some arguments against *any* discounting have been advanced. The main objection to discounting is that events (such as genetic changes) that may happen far into the future are so heavily discounted that they are virtually disregarded in conventional analysis. Thus society may be making Faustian bargains that provide short-term advantages but that could be bitterly regretted by future generations. This subject is discussed in detail in Appendix E, where a pragmatic solution to the problem is suggested.

This study proposes discounting over a normal project life of approximately one generation, but no *further* discounting of effects that occur beyond that period (i.e., the discount factor is held constant for any year that is beyond one generation from project inception). This solution is attractive because it simulates conventional business decisionmaking procedures over normal project lives (which rarely exceed two or three decades, i.e., one generation), but it avoids excessive discounting of the very distant future. Some justifications for this approach are advanced in Appendix E. Note, however, that with this procedure, it is only possible to use lump sum valuations of threats (e.g., a one-shot cleanup cost, replacement cost, etc.) if the period of evaluation is infinite. Any annual cost continuing for an infinite period (such as maintenance cost for perpetual care) will have an infinite present value if it is not continuously discounted. Thus where no lump sum equivalent can be found to replace a continuing cost, the planning horizon must be limited or conventional discounting must be employed.

The Optimum Timing of Projects--

A substantial body of literature deals with the optimum timing of projects. For example, it can be shown that the time profile of the stream of benefits or income can be such that net present value is maximized by delaying project inception (see Herfindahl and Kneese, 1974). This situation could apply to some pollution abatement projects because the annual benefits (which are damages averted) increase rapidly or abruptly during the project life. For example, it might pay to delay the construction of an effluent treatment plant because the quantity of effluent or its potential for environmental damage is expected to increase in the future.

Another situation in which delay can be beneficial is where there is uncertainty about the magnitude of future benefits, and where delay permits additional data to be obtained. This benefit of reducing uncertainty can be regarded as an option value (see Appendix C), and could be particularly significant in hazardous waste management where the irreversible impacts of the use of a particular technique are not well defined. In this event, it could be an advantage to society to delay taking an essentially irreversible action (such as deep well injection of a waste) until further research and analysis of the impacts of this action can be completed. During the intervening period, it would be necessary to use a management technique (such as engineered storage) that has a low potential for adverse impact (both in terms of low expected impact and limited uncertainty about the impacts) but is unsuitable as a long-term solution because of high cost or some other reason (such as limited capacity).

USE OF THREAT SCENARIOS

The most difficult part of any economic analysis of pollution control problems is almost invariably that of determining damages. According to Fisher and Peterson (1976), there are four stages in the assessment of damages from conventional pollution sources, as shown in the upper part of Figure 7. Starting with a specified emission or waste discharge, the ambient conditions and the physical effects must be determined before the dollar damage costs can be estimated. Again, note that there will be effects that are difficult to quantify in dollar terms. To extend the Fisher and Peterson model to hazardous wastes, it is necessary to add one preliminary stage: Identification of the possible threat mechanisms. This stage is necessary because the nature of most hazardous waste management problems is such that the management techniques used present a variety of threats of adverse environmental impacts, whereas conventional pollution control analysis usually centers on the effects of a known waste stream discharged to a specified environment.

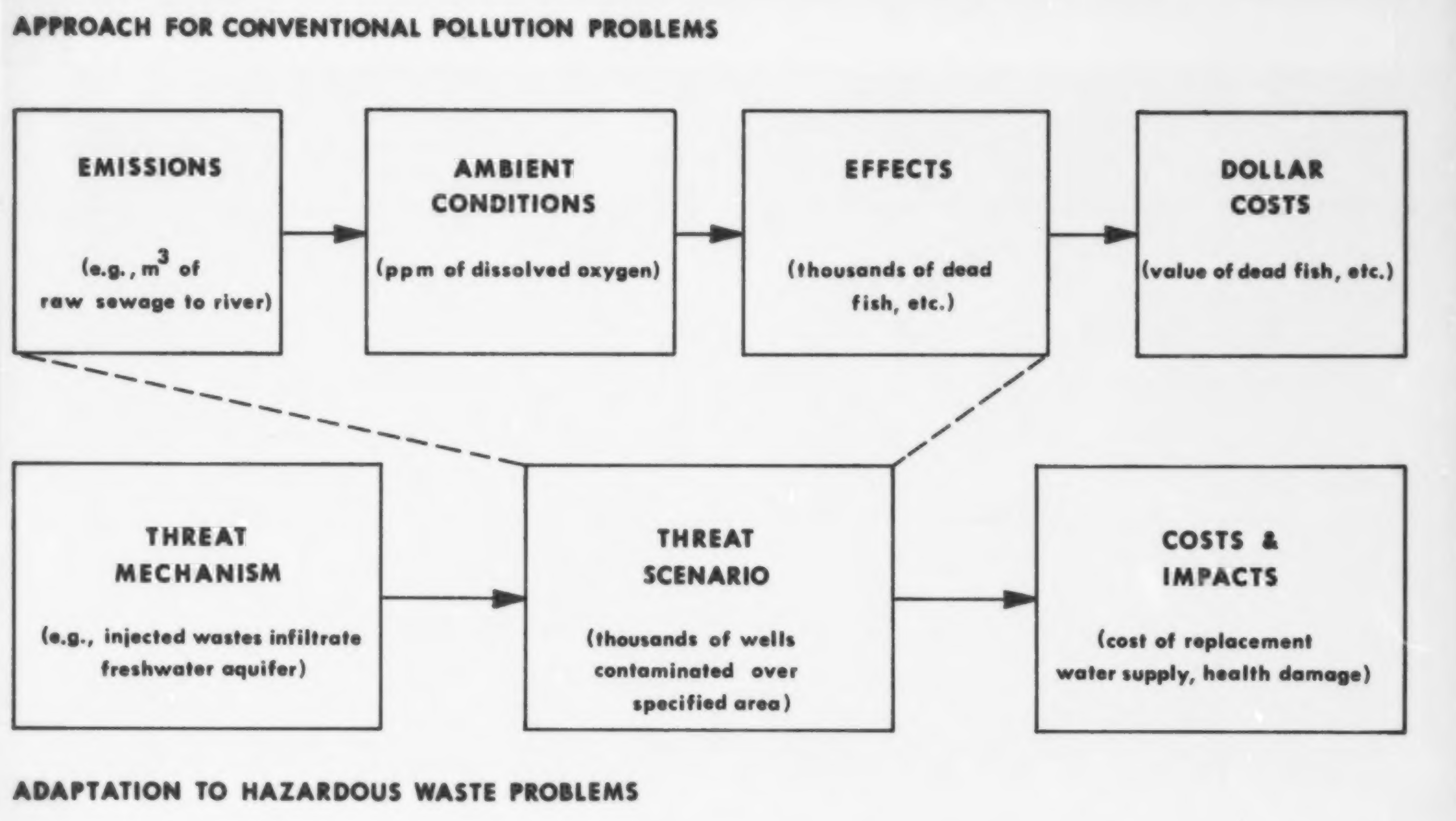
APPROACH FOR CONVENTIONAL POLLUTION PROBLEMS
EMISSIONS
(e.g., m3 of raw sewage to river)
AMBIENT CONDITIONS
(ppm of dissolved oxygen)
EFFECTS
(thousands of dead fish, etc.)
DOLLAR COSTS
(value of dead fish, etc.)
THREAT MECHANISM
(e.g., injected wastes infiltrate freshwater aquifer)
THREAT SCENARIO
(thousands of wells contaminated over specified area)
COSTS & IMPACTS
(cost of replacement water supply, health damage)
ADAPTATION TO HAZARDOUS WASTE PROBLEMS

Figure 7. Process for assessing damages associated with hazardous waste management.

In principle, it is possible to model environmental impacts and hence arrive at dollar values for the damages attributable to the use of any technique, using willingness-to-pay where necessary. In practice, however, this can be a far from simple procedure and could require considerable resources. For each technique, it might be necessary to consider several threat mechanisms, while each mechanism could probably cause impacts with a variety of magnitudes, depending, for example, on ambient conditions. Waste stream variability could further compound the number of cases to be considered in the physical modeling. Hence assuming adequate data were available, the dollar damages would ideally be expressed, not as a point estimate, but as a probability distribution of costs. The ways in which these costs would fall on the various parties-at-interest could also vary from situation to situation. Furthermore, as shown in Appendix F, the way in which individuals perceive a risk or threat may be more important in determining their responses than the actual magnitudes and dollar sums associated with that threat.

The sheer complexity and the fact that the probabilistic approach outlined above fails to recognize perceptions of threats are good reasons why this approach may not be an appropriate tool for many hazardous waste decisions. The problem of perception could be partly overcome by modeling the physical effects and then asking the parties-at-interest how they would respond to these threats. However, this approach would not overcome the difficulty (so apparent with nuclear power) that the public may not trust experts' assessments of threats. Furthermore, under most circumstances many of the necessary data are unavailable and those that are available are fuzzy. To generate the missing data and refine those that are available could be a major task, requiring a level of effort that is simply not available or that is beyond that justified either by the nature of the decision to be made or by the sophistication of the available techniques for modeling and valuing effects. Even where this probabilistic approach is conscientiously followed through in detail, there are numerous possible sources of error and bias (Slovic and Fischhoff, in press).

An objective of this research was to develop an analytical methodology that does not involve detailed analysis and that does not require extensive data. A central concept of the proposed methodology is to replace the first three stages of the conventional damage model (emissions, ambient conditions, and effects) by a threat scenario, as illustrated in the lower part of Figure 7. The scenario describes what might typically happen in the event that any specified threat should become a reality. Where appropriate, more than one scenario could be used to cover different threat mechanisms or different outcomes arising from a given mechanism.

Judgment will be necessary to limit the number of scenarios that are considered. As shown in Section 4, there are usually numerous possible threats. The analyst should pick those that appear to be comparatively likely, those that (as far as is known) could have particularly disastrous consequences, and those with which the general public or certain parties-at-interest are especially concerned. In practice (as illustrated in Section 6), reducing the number of scenarios to manageable proportions may not be as difficult as it appears at first sight, since in a given situation, there may be a consensus on the threats that are significant.

Though merely qualitative descriptions of threats would be useful, typical quantitative data should be suggested when possible. These would reflect judgments based on the results of modeling studies, actual experience with that type of threat, or worst case assumptions. Where site-specific modeling of threats is not feasible, the analyst may be able to adapt some of the available analyses or case studies of hazardous waste damage incidents to meet his needs (see Appendix B).

A major difficulty with the use of typical threats taken from actual experience elsewhere will be to choose a magnitude or scope for the impact that is appropriate to the types and quantities of wastes concerned and to the local circumstances (e.g., geohydrologic conditions). However, simple worst case assumptions could be useful to place limits on some impacts. For example, in evaluating the effect of landfill leaching, the assumption could be made that after many years, a steady state is achieved in which the leachate contains the same quantities of nondegradable toxic elements that enter the landfill and that this leachate enters the local river system without attenuation. If the streamflow is known, the average concentration of toxic elements in the river could be calculated, and the effect on aquatic life could be predicted. Another approach to the same problem would be to assume that any leachate was normally highly attenuated (e.g., by ion exchange) before it left the vicinity of the landfill, but to estimate a cleanup cost represented by the cost of installing and pumping a sufficient number of interceptor wells to contain the leachate should it become necessary.

Though admittedly simplistic, the threat scenario approach overcomes or avoids many of the difficulties associated with the more detailed probabilistic approach. It can accommodate whatever data are available, but perhaps its most attractive feature is that it recognizes the sociological dimensions of a decision situation. Threat scenarios can be constructed to reflect or include actual public perceptions and concerns. The attitudes and behavior of parties-at-interest can be predicted, and decisions can take these factors into account. In many respects, the absence of accurate qualitative data need not be of undue concern, the decisionmaker is largely interested in the reactions of individuals to the threats from hazardous waste management alternatives. In many cases these are likely to reflect what has happened in the past, even if the circumstances are different. For example, individuals tend to rely on recent experience when making judgments on the probability and maximum (expected) magnitude of an event, such as a flood. (See Slovic, Kunreuther, and White, 1974; Slovic, Fischhoff, and Lichtenstein, 1976; and Slovic and Fischhoff, in press.) Thus the mere identification of threats is an important part of this methodology, even if the magnitudes of the threat impacts and the probabilities of their occurrence are ill-defined.

PREREQUISITE INFORMATION FOR ANALYSIS

Obtaining prerequisite information is the first phase in applying the methodology. Four steps must be taken to provide the inputs necessary for analysis:

(1) Define the scope of the study in terms of both the type of waste and the geographic area to be considered;

(2) Obtain an inventory of the existing hazardous waste situation, including both generation and disposal;

(3) Determine how the hazardous wastes are currently controlled within the study area;

(4) Ascertain policy objectives for hazardous waste control.

These steps are discussed in the following subsections.

Defining the Scope of the Study

The first step in collecting input for analysis is deciding on the scope of the study. The geographic scope is usually dictated by the terms of reference of the study and is likely to correspond to a political division or unit such as a State or a planning region. If any choice is possible, it is desirable that the area chosen be geographically isolated. Otherwise, wastes crossing the study area boundaries could complicate analysis. For example, where two separate political units share a major metropolitan area, there could be difficulties if the two units adopted significantly different hazardous waste management policies, possibly leading to waste transfers between the units that would be unlikely to promote overall economic efficiency.

Two aspects of waste type need to be considered. The source-related categories of waste, and within these categories, the choice of a definition of hazardous waste. Although this study is oriented toward industrial (process) wastes, the general methodology could be adapted to cover a wide range of potentially hazardous wastes. Since these wastes tend to have different characteristics (largely in terms of type of generator and frequency of generation, also with regard to degree of exposure to the hazard), they may ideally require different management policies. For example, it is unlikely that exactly the same approach toward waste management would be ideal for large recurrent quantities of industrial process wastes, occasional obsolete laboratory chemicals, and empty pesticide containers. Because of these differences, it may be desirable to limit the scope of any study to insure that the wastes considered exhibit some degree of homogeneity, or alternatively to consider different approaches for different wastes. Furthermore, the agency conducting the study may not have, or may not wish to exercise control over certain categories of wastes (e.g., Department of Defense wastes). Some categories of waste may already be adequately controlled (this could be the case for radioactive wastes), and therefore additional study would be unnecessary. Hence some limitation of the scope of the study will probably be necessary. (The major source-related categories of potentially hazardous wastes were listed in Section 3.)

Within the source-related categories of waste, there remains the problem of deciding which wastes are hazardous. Where a definition is not mandated it is practical to start off with a broad working definition and narrow it down as the study data are analyzed. However, certain marginally hazardous wastes could be eliminated at the outset if it would be impractical to regulate them in the same way as the other hazardous wastes. Waste oil (other than perhaps that from the oil refining and re-refining industries) is a good example of such a waste. The use of oils in the engineering industries is so widespread that it is difficult to control their disposal in small quantities. In view of the comparatively limited threat that waste oil poses to the environment, it is often omitted from hazardous waste studies (Stradley, Dawson, and Cone, 1975).

Of course, in addition to studies that cover all hazardous wastes, studies can be conducted on the wastes of a single industry (e.g., pesticide manufacture) or on the disposal of a particular waste (such as PCB's) or wastes containing a particular element (mecury, for example). For single industry studies, the industry can be defined by its SIC number (Statistical Policy Division, Executive Office of the President, 1974). This approach works well for some industries such as the basic process industries (e.g., copper smelting), but care must be exercised when dealing with diverse industries (such as electronics) that can appear under many different SIC numbers.

For studies that deal with a particular waste or element, the main problem will be to define the concentration or quantity that qualifies as hazardous. For example, even in the absence of industrial sources, sewage sludge usually contains low concentrations of some heavy metals that originate from plumbing fixtures. (Personal communication, W.L. Ross, Denver Research Institute, Denver, Colorado, September 1977.) However, though sewage sludge is not without its disposal problems, this sludge would not usually be regarded as a hazardous waste. The solution to this type of problem is to establish cutoff concentrations and/or quantities.

Taking Inventory of the Existing Hazardous Waste Situation

Before any economic analysis can be performed, it is necessary to obtain a general picture of the existing hazardous waste situation within the study area. The information required depends on the precise objectives of the study, but in most cases it would be appropriate to obtain the following data:

1. Sources of wastes (SIC categories and locations);
2. Types of wastes;
3. Annual quantities;
4. Current dispositions of wastes.

EPA has published a guide to conducting hazardous waste surveys (Porter, 1975), but a more detailed appreciation of what might be involved could be obtained by reviewing one of the State or industry surveys (depending on the orientation of the study).

The critical aspect of any hazardous waste survey lies in the way in which the assessment of waste generation is approached. There are three principal approaches that can be used:

1. Attempt to inventory all hazardous waste sources;

2. Sample hazardous waste sources and extrapolate to estimate total study area waste on the basis of industrial employment, physical output, or value added within SIC categories;

3. Use waste generation factors (e.g., tonnes/year per employee for a given SIC category) obtained from national studies, together with study area employment, physical output, or value added by SIC category to estimate total study area waste generation.

Clearly, the first method is the most accurate, but it has rarely been used because of the high cost. To date, it has only been feasible where there were a limited number of firms involved, as in certain industry studies and some State and regional studies. For example, this approach was adopted for some sectors in the study of hazardous waste practices in the nonferrous smelting industries (Leonard et al., 1975), and it was attempted by Battelle Memorial Institute, Pacific Northwest Laboratories in their study of hazardous waste management in EPA Region X (Stradley, Dawson, and Cone, 1975). In the future, under Section 3002 of PL 94-580, data should be available for all generators of such wastes as are deemed hazardous under Section 3001 of that law. However, data would not be available for wastes that were not deemed hazardous under the above law, and hence studies that addressed other wastes would still need to collect information. Note that even with a general study at the State level, for example, it would be virtually impossible to inventory every organization that might occasionally have small quantities of hazardous wastes.

The second approach (extrapolating from a sample), has been by far the most frequently used to date. For example, this approach was used in a study of hazardous wastes in Massachusetts (Fennelly et al., 1976) and in a study of hazardous waste management in the pharmaceutical industry (Arthur D. Little, Inc., 1976). A common method is to attempt to obtain data from all the major generators and then to assume that the smaller ones produce the same proportion of waste per unit of physical output (process industries producing a single major output) per employee or (less commonly) per value added dollar. The disadvantage to this method is that it implies that the process technology used in the smaller firms is similar to that in the large firms. Since small firms are rarely miniature versions of large firms, this assumption can lead to significant error. A further drawback to this method is that unless there are additional independent data, the disposition of wastes from the smaller firms will be unknown.

The third approach (use of waste generation factors) is inexpensive but is liable to be of questionable accuracy, because in addition to the deficiencies noted above, it does not take account of regional differences in technology or (for the per employee and value added versions) of differences in labor productivity, etc. A hazardous waste generation study for the Twin Cities area, Minnesota, used this approach in part (Barr Engineering Co., 1973).

A fourth approach, that is something of a hybrid between all three approaches, involves the development of a series of model plants. These plants would be of different sizes and would use different processes. Hence any particular industry structure could be simulated by specifying an appropriate mix of model plants. For example, largely because of the paucity of survey data, this approach was adopted in the study of hazardous waste management in the electroplating and metal finishing industries (Battelle-Columbus Laboratories, 1976).

While collecting data on the quantities and types of wastes generated in the study area, it is also convenient to collect data on existing disposition. However, to some extent, an independent check on wastes within the study area can be made by obtaining data on wastes being sent for various forms of disposal (e.g., landfilling at licensed sites) and resource recovery. These data will not reveal the extent of uncontrolled waste disposal or storage at a manufacturer's site, so this approach cannot be substituted for some sort of study of waste generation. However, waste disposal data can provide a supplementary source of information about hazardous waste generation (e.g., by identifying hazardous waste generators in unexpected SIC categories) and can permit checks on the quantity estimates of some firms.

Many waste surveys also include estimates of future waste generation. This can be particularly significant when new air and water pollution controls are expected to lead to additional wastes for disposal (e.g., scrubber and water treatment sludges) or where process technology is undergoing change. Estimates are available for the solid wastes expected to be generated as a result of the Federal Water Pollution Control Act Amendments of 1972, the Marine Protection, Research and Sanctuaries Act of 1972, and the Clean Air Act of 1970 (Stone et al., 1974). However, the available waste disposal options (and their costs) may influence the quantities of wastes that are generated, so prediction of future waste generation will be considered later in the analysis.

Determining How Hazardous Wastes Are Currently Controlled

The existing situation or status quo of hazardous waste generation and disposition makes a useful base case against which to measure changes that might result from various alternative approaches. Hence it is also necessary to determine how hazardous wastes in the study area are controlled.

In addition to explicit controls, such as mandating ultimate disposal of certain wastes at a chemical landfill or other approved facility, there may be indirect controls that must be identified. For example, regular landfills in the study area might be prohibited or restricted in accepting industrial wastes. Even if these restrictions were not scrupulously adhered to (as may well be the case in practice), the effect would be to divert most hazardous wastes to alternative forms of disposal or to land disposal within another jurisdiction that does not have such restrictions. It is therefore necessary to examine rules and regulations, licensing requirements and practices in order to seek out indirect ways in which hazardous wastes are controlled. The Clean Air Act Amendments of 1970 (PL 91-604) and the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) are ubiquitous examples of such indirect controls, which, although not specifically directed toward hazardous waste (other than Section 112 of PL 91-604), nevertheless have a major impact on hazardous waste management. Several other Federal laws can have generally minor impacts (see Section 3), and in addition, there will be many State (and sometimes local) laws and ordinances that also exert indirect influence. An important feature of much of this legislation is that it is not the actual statutes, but the administrative proscriptions and decisions that are important (Haskell and Price, 1973). Hence to establish how hazardous wastes are controlled under the status quo, it is important to examine these administrative decisions and their enforcement.

Ascertaining Policy Objectives

The final prerequisite is to ascertain the policy objectives that will govern the approach that is adopted to control hazardous wastes. Policy objectives generally deal with normative issues, and it is not infrequent that optimization of a given approach, or choice between approaches, will require trade-offs between achievement of different objectives. The goal of economic efficiency in the allocation of resources (i.e., striving toward a potential Pareto optimum) is usually assumed without question (Haveman and Weisbrod, 1975; Planning Branch, Treasury Board Secretariat, 1976), even though it may not be achievable in practice. Other policy objectives might cover the following topics:

1. What is regarded as equitable, and the extent to which departures from an equitable situation can be tolerated;

2. The extent to which policies should reflect risk aversion;

3. Preferences for the use of taxation and economic incentives as policy tools;

4. The degree to which government should proscribe and regulate, as opposed to relying on market forces backed up by the judicial process for determining liability questions;

5. The degree of autonomy permitted to relevant individual jurisdictions, agencies, etc.

Some policy objectives may not be specifically stated, but they will constitute a tradition of that agency, or they may reflect the mores of that society.

When policy objectives (including implied objectives) are not sufficiently detailed or complete, it is probably best to apply the methodology to the evaluation of various feasible alternative approaches, and then highlight policy implications along with other information required for decisionmaking. It may also be found that it is not possible to devise approaches that satisfy all the policy objectives. For example, it may not be feasible to achieve economic efficiency as a result of uncorrectable market failures, or there may be trade-offs between the efficiency and equity that can be attained. In this case, the most expeditious procedure would be to consider a variety of approaches that look as though they may come reasonably close to meeting the objectives. When the outcomes of using these approaches have been determined, any shortfalls in meeting objectives can be identified and brought to the decisionmakers' attention.

THE ANALYTICAL FRAMEWORK

Applying the analytical framework is the second phase in the use of the methodology. The sequential steps involved in applying the analytical framework are as follows:

(1) Develop alternative approaches for hazardous waste management.

For each approach under consideration:

(2) Allocate wastes to techniques;

(3) Develop threat scenarios, list other impacts;

(4) Determine economic and social effects;

(5) Determine impacts on the parties-at-interest;

(6) Project responses of the parties-at-interest;

(7) Predict physical outcomes;

(8) Enumerate costs and impacts;

(9) Reiterate Steps 2 through 8 as required.

Each step is discussed below. Because these steps closely follow the interaction model (Figure 5) discussed in Section 4, there is some overlap with that discussion. However, in Section 4 the orientation was behavioral, whereas that which follows is intended to provide practical guidance.

Development of Alternative Approaches to Hazardous Waste Management (Step 1)

Each approach represents an alternative general philosophy or actual strategy for managing hazardous waste that is broadly consistent with the policy objectives. For example, one approach could be to require all hazardous wastes either to be detoxified or to be disposed of in a chemical landfill. Another example could be an incentive approach to encourage disposal at chemical landfills by subsidizing their operation. Different definitions of hazardous waste and what constitutes detoxification, or different levels of subsidy would be considered as falling within one approach. Thus an approach is a general strategy rather than a detailed plan.

In the author's terminology, approaches may be either positive or negative and specific or influencing. A positive approach directs actions toward a solution or form of management, whereas a negative approach directs action away from something. In the case of specific approaches, requirements are spelled out; thus a specific positive approach would mandate something, such as the use of a particular pollution control technology. Conversely a specific negative approach would ban something, such as the use of a particular means of waste disposal. On the other hand, influencing approaches attempt to encourage or discourage an action (e.g., by using economic incentives) as opposed to mandating something. This distinction is important when the linkage between approaches to hazardous waste management and techniques for the control of hazardous waste is examined.

In most situations, it will be appropriate to include the status quo as a base case, even though it may prove difficult to define the approach that it represents. The principal advantage of using a base case is that the effects and outcomes of the various approaches can be expressed as changes with respect to this case, and it is often easier to determine changes in some parameter, as opposed to calculating absolute values. For example, it can be very difficult to determine the total magnitude of the consumers' surplus, whereas the size of a small change can often be estimated with comparative ease. Aesthetic and existence values must be evaluated in terms of changes (see Appendix C). The status quo is often a good starting point, as people are familiar with it and are largely concerned with changes from the existing situation. However, in some circumstances, a base case other than the status quo might be appropriate. This could occur when some major new development (such as a change in the law, a major new waste-generating plant, or a new disposal facility) is already underway. In these situations, the base case would need to reflect such developments.

Allocation of Wastes to Techniques (Step 2)

As a preliminary action, it is necessary to determine which waste management techniques should be considered (see Appendix A). Techniques can be ruled out for a variety of reasons, including local infeasibility (e.g., lagooning for evaporation in wet climates), technical infeasibility (e.g., biological treatment when there are no biodegradable wastes), conflict with policy or objectives (e.g., the use of ocean dumping), and excessive cost (e.g., space disposal for most wastes). Clearly, one has to be careful about eliminating disposal techniques on economic grounds before economic analysis has been conducted. However, there may be some situations in which one technique has a very high control cost and appears to provide no offsetting advantages over a technique that has a much lower control cost. If the parties-at-interest are similar for both, then it would be reasonable to eliminate the technique with the higher control cost.

The next action is to try to predict which techniques will be used to control what wastes. Each approach will have a different influence on the techniques that are used. In the case of a specific positive approach the linkage will be direct--that is, the technique(s) will be mandated. However, in all other cases, including those that represent combinations of the types of approach, the linkage is indirect. For an influencing approach the dispositions of wastes are steered toward or away from certain control techniques, but all feasible techniques are still theoretically available. In the case of a specific negative approach, the available options are reduced by the elimination of one or more techniques, but other factors determine which techniques are used for what wastes. These factors are the normal economic forces in which a firm generally minimizes its own (internal) costs, tempered by the desire to minimize managerial effort (which is really a cost to the firm). This is equivalent to minimizing generator's cost (see Appendix C) and will cause firms to *favor* the use of certain disposal techniques. However, the techniques that are actually used will be influenced by the actions of the various parties-at-interest, and the desires of the firms to avoid risk. Because *outcomes* have yet to be predicted at this stage in the evaluation process, only a tentative allocation of wastes to techniques can be made.

A difficulty arises when waste stream changes and treatment techniques (as opposed to disposal techniques) are being considered. For the common regional situation where a wide variety of wastes are produced by many generators, it will not be feasible to examine changes that may occur on most of the generators' sites. Changes in the opportunities for and costs of disposal techniques could cause generators to change waste streams and treatment methods. In this event, some broad assumptions about such changes will have to be made, or such changes disregarded (as already noted, waste disposal costs are usually only a small portion of product value, which suggests that onsite operations may not be very sensitive to offsite disposal costs). However, where there are major regional industries producing substantial quantities of reasonably homogeneous wastes (e.g., petroleum refining in Texas), further investigation would clearly be warranted.

Development of Threat Scenarios, Etc. (Step 3)

The identification and description of threats has been discussed in Section 4 and Appendix B, and the philosophy of using threat scenarios was expounded earlier in this section. To proceed with the analysis, it is necessary to identify one or more threats for each technique being considered. In many cases, it will be possible to establish that, for a given technique, one threat is of far greater import than all others. In this event, that threat scenario should be developed as fully as possible, and other less significant threats can merely be identified. However, an attractive feature of the methodology is that it provides a flexible framework for analysis that can readily accommodate inputs from a variety of sources. Waste management personnel, for example, may generate the threat scenarios that they consider to be the most relevant to a given situation. If, however, it becomes apparent that the public is largely concerned with some other threat, an appropriate scenario can be added without disrupting or contradicting the previous work.

The quantitative data used to describe threat scenarios should probably be kept simple. For example, means, modes and possibly ranges can be used rather than probability distributions for effects. More detailed data may be appropriate when the waste management alternatives have been narrowed down to two or three options.

Environmental impacts of hazardous waste management techniques other than those that arise through threats can also be listed. These impacts are all related to resource use (i.e., energy consumption, materials, and land use). Though this aspect of environmental impact is accounted for via the cost mechanisms (for example, the control cost for land disposal includes the cost of land and energy used), there are many who consider that the market prices for some resources, such as energy, may not reflect their true values to society. Hence there is frequently additional interest in resource use, and for this reason, identification of these data is helpful.

Determination of Economic and Social Effects (Step 4)

This process, which leads to the evaluation of some of the costs and impacts (see Figure 5) was discussed in Section 4. Effects should be evaluated for each of the techniques involved in any approach being considered.

Determination of the Impacts on the Parties-at-Interest (Step 5)

Determination of the economic and social effects leads directly to determination of the parties-at-interest. Section 4 provides some generalizations about attitudes and behavior of the parties-at-interest. These data can be used to examine the nature and degree of impact that a waste management technique may have on a party-at-interest.

Though predicting individual responses of the parties-at-interest (the next step) may be important, a general analysis of the impacts of the use of the various techniques on the parties-at-interest can be a powerful tool when it comes to comparing the effects of the use of different techniques, and hence, alternative aproaches. Table 7 presents a matrix of the parties-at-interest for each major technique and suggests the nature of the effect that use of the technique has on each party-at-interest. This is a generalized matrix and in any specific situation the effects could differ from those indicated in Table 7, and there could be additional parties-at-interest. Note that where a reference level was necessary to determine the nature of the impact, each technique has been compared with temporary storage at the generator's site. Although not an acceptable long-term solution, this situation represents a common starting point. In other situations, the status quo or a base case could be used as a reference level.

It may be useful to examine a few of the entries in Table 7 to understand how judgments about the nature of the effects were made. Consider, for example, a technique involving chemical treatment to reduce hazard potential. Management of the firm generating the waste will have mixed views about the technique (+-), as it is likely to be comparatively costly; but treatment should reduce the risk of an adverse incident. The firm's workers are likely to favor treatment (+) because it probably makes their job safer. The effect on the waste disposal and transport industries will depend on the process streams following treatment (+-); they may have safer wastes to dispose of (+), or there may be no waste requiring offsite disposal (-). Local officials are likely to favor chemical treatment because of the reduced risk of an environmental incident (+), but water supply authorities might be concerned

TABLE 7. MATRIX OF EFFECTS ON THE PARTIES-AT-INTEREST

Nature of effects are:

- ++ Favorable
- + Somewhat favorable
- +- Mixed, or depends on circumstances
- - Somewhat adverse
- -- Adverse
- ☐ Not significant

Party-at-interest

Hazardous waste control technique	Waste generators-management	Waste generators-workers	Competing firms (different process)	Waste disposal industry	Waste transporters	Secondary materials industry	Local political officials	Local environmental officials	Local residents and workers	Local property owners	Water supply authorities	Local water supply users	Fishermen (freshwater and ocean)	Recreation related industry	Environmentalists	Scientists	Other	Other parties-at-interest
Change in waste stream	+-	+-	+-	+-	+-	+	+	+			+-				+			
Resource recovery	+-	+-	+-	-	+-	++	+	+			+				++		-	Virgin material suppliers
Treatment - physical	+-	+	+-	+-	+-	+	+	+			+-		+-		+			
- chemical	+-	+	+-	+-	+-	+	+	+			+-		+-		+		+	Chemical suppliers
- biological	-	+-	+-	-	-	-	+-	+-			-		-		+-			
- thermal	+-	+-	+	-	-	-	+-	+-	-	-	+				+-			
- encapsulation	-	+	+	+	++	-	+	++			+				++			
Land application	+	+	+-	+-	+	-	-	+-	-	-	-	-	-		-		+-	Farmers
Landfill - secure	+-	+	++	++	++	-	+	+	-		+	+-			+			
- ordinary	+	+-	-	+	+-	-	-	-	--	-	-	-	-		-			
Mine disposal	-	+	++	++	++	+-	++	++			+				++		-	Adjacent mineral interests
Lagooning	+-	+-	-	-	--	-	-	-	--	-	-	-	-		--		-	Fowl hunters, farmers
Deep well injection	+	+	-	+-	+-	--	-	--		-	-	-			-	-		
Ocean dumping	+	+	-	++	+	-	-	--	-	-	+		--	-	--	--	-	Other nations, politicians
Engineered storage	-	+	+	+	-	+-	+-	+-	-		+	+-			+-			
Space disposal	--	+	+	+-	+	-	-	-			++				--	-	-	Other nations, politicians
Discharge to sewer	+	+	-	--	--	-	-	-			-				-		--	Sewer authorities
Discharge to waterway	++	+	--	--	--	-	--	--	-	-	--	-	--	-	--	-	--	Other water recreationists

over the possible discharge of an undesirable effluent to a river that constitutes part of a water supply (-). Though water supply authorities and environmentalists are likely to have definite views on most techniques, the perception of threats and benefits from chemical treatment may be remote to most local residents (no entry in Table 7). Thermal treatment, on the other hand, which could cause the deterioration of local air quality, might be viewed negatively by many residents and property owners (-), and a technique such as lagooning might pose a discernible threat to local water supply users (-).

In identifying and evaluating impacts in Table 7, each party-at-interest was assumed to represent only one viewpoint. But any individual could fall into more than one category of party-at-interest; for example, one person could be a local resident, property owner, worker and environmentalist. In Table 7, the attitudes of the parties-at-interest are "pure;" For example, business management is assumed to adopt only those attitudes characteristic of firms (see Section 4). In the event that the chief executive of a firm happened to be a strong environmentalist, that particular firm would probably exhibit some mixed behavior. However, this is not allowed for in Table 7, where the impacts on waste generators-management and environmentalists are maintained separately.

To apply the parties-at-interest matrix to a specific situation, it might sometimes be more appropriate to conduct the analysis in terms of approaches (which could encompass more than one technique), rather than techniques.

Projection of Responses of the Parties-at-Interest (Step 6)

Attitudes that predispose the parties-at-interest toward certain responses were discussed in Section 4, along with some likely responses.

Responses include a variety of actions, ranging from raising the price of a product to cover increased hazardous waste management costs, to public protest about potential adverse effects. Individual responses can, to an extent, be predicted from a knowledge of the situation and the parties-at-interest. In evaluating approaches, it is useful to note possible responses, even if these are not certain. Some responses are in the nature of threats--for example, requirement of costly disposal techniques increases the threat of illicit disposal (dumping) of wastes.

Prediction of Physical Outcomes (Step 7)

The physical outcomes include the waste dispositions and some of the responses of the parties-at-interest (such as householders moving to avoid threats or actual pollution, or fishermen avoiding depleted fisheries). Waste dispositions (including the nondisposal options such as process change and resource recovery) are largely determined by the initial allocation of wastes to techniques, described under Step 2. If there were no socioeconomic interaction (or policy level feedback), simple cost minimization should determine the ways in which the firms choose to distribute their wastes among the available techniques. However, the responses of the parties-at-interest may also affect the outcomes. For example, some parties-at-interest might oppose the use of certain techniques, and their actions might thereby render them unavailable to the waste generators or cause them to become less attractive than others because of this opposition. For these reasons, waste dispositions other than those based on minimization of a generator's cost may be chosen.

At this stage, it is also appropriate to consider how the quantities of wastes will change in the future. Although data on the price elasticity of demand for industrial waste disposal services are rare, it can be expected that the quantities generated will exhibit some response to price, as increased disposal costs will encourage in-plant treatment, volume reduction, and resource recovery. Known plans for new plants or expansions of existing ones can be factored in at this stage, but it should be noted that waste generators will probably use state-of-the-art technology, and in some cases will replace less advanced systems. Hence even if economic activity in the study area is expected to grow, the quantities of wastes requiring disposal may not increase at the same rate.

Environmental threats can also be listed as outcomes. Of course, only those that materialize constitute actual physical outcomes, but it does not seem appropriate to segregate definite (though ill-defined) outcomes such as those of ocean dumping from those such as lagoon overflow that are probabilistic in nature. All are possible outcomes, but few if any are clearly defined.

Enumeration of Costs and Impacts (Step 8)

Once the waste dispositions are determined, it is possible to list all the costs associated with that particular approach to hazardous waste management. These include the generators' costs that are associated directly with the disposition of the wastes, and the other costs of control (i.e., the administrative and social control costs).

In addition to these costs, there may be some definite environmental costs or social impacts that can be specified, such as changes in property values and noise insult to residents along a road leading to a landfill. As discussed in Section 4, the dividing line between environmental costs and social impacts is not clearcut and is based largely on the feasibility of quantifying costs.

Many of the environmental costs and social impacts arising from an approach to hazardous waste management will be associated with threats. These should be listed as part of each threat scenario, which should also include an estimate of the probability of the threat's occurrence (if a realistic estimate can be made).

Though all costs should be specified in constant dollars without allowing for future inflation, they should also be discounted using whatever rate or approach is chosen (as discussed earlier in this section). Where threats are concerned, it will normally involve choosing a time at which the threat is assumed to materialize. Where a process such as leaching is involved, it may be possible to use engineering judgment to decide the earliest likely time that a threat may materialize. Where events are completely random, the analyst will be forced to use some arbitrary assumption such as halfway through the planning period, or at the end of one generation. If the recommended approach of not discounting beyond one generation is employed, threat materialization at the end of one generation is in many respects an attractive choice, since if it occurs afterwards, the actual time of materialization will not affect the discounted values.

Reiteration of Procedure (Step 9)

Once the above procedure has been carried out and the physical outcomes, costs, and impacts associated with any approach are predicted, there is feedback to the policy level. An analyst can examine the results for each approach, can test them against the policy objectives, and can modify the approaches to improve the results. In this way, he can optimize the results within a given approach by making one or more iterations of the evaluation procedure (Steps 2 through 8). For example, the analyst could change the number and location of landfills to arrive at a least-cost land disposal solution, or he could change the levels of taxes or subsidies to enhance effectiveness or correct the equity of a situation. Once optimization of each approach is reasonably complete, the decisionmaker is in a position to compare the results of different approaches. However, sometimes it may be necessary to design a new or hybrid approach.

AIDS TO DECISIONMAKING

Decisionmaking is the third phase in applying the methodology, and involves five steps as follows:

1. Array the alternatives;
2. Eliminate approaches that are dominated by others;
3. Check each approach against policy objectives;
4. Examine trade-offs between known costs and threats;
5. Select an approach, using an appropriate degree of risk aversion.

The decisionmaking phase is illustrated in Sections 6 and 7. However, some aspects of decisionmaking are discussed below.

Arraying the Alternatives

Once the framework described above has been applied to each approach being considered, the decisionmaker must choose among approaches or develop new ones. Cost-benefit and risk-benefit analyses usually seek to reduce all effects to dollar terms so that the alternative that has the greatest net present value can be selected. A simple refinement would be to choose only among those alternatives that also passed certain other tests, such as equity and government cost criteria. Although the methodology presented here draws strongly on the techniques of cost-benefit and risk-benefit analysis, reducing all data to dollar terms suppresses too much information for environmental planning.

There have been a variety of approaches proposed for systematizing the decisionmaking process where there are complex considerations such as multiple objectives. Some tend toward the use of a utility-based approach, often in conjunction with event trees to cope with alternative outcomes (e.g., Bell, Keeney and Raiffa, 1977; Wendt and Vlek, 1975; Fishburn, 1964; and Schlaifer, 1967). This does, however, involve selecting a utility function which then essentially represents part of the policy objectives of the agency or decisionmaker. The use of simple scales (both ordinal and cardinal) for achievement with respect to a number of objectives, and ranking systems that combine such scales is commonly used in marketing and in corporate planning and could be useful here. Sewell (1973) discusses a variety of evaluation techniques that have been used for resource-oriented problems.

The approach proposed here is to use a balance sheet format which sets out for each approach the costs and threats, their effects on the parties-at-interest, possible responses of the latter, and the physical outcomes. The decisionmaker is then in a position to select his own trade-offs between the approaches. If maintaining the status quo is used as a base case, whatever approach is chosen should represent an improvement (at least by the decisionmaker's measuring rod). This is equivalent to requiring that a project assessed by traditional cost-benefit techniques has a benefit/cost ratio greater than unity.

Some methods that may be used to handle the data and present them to the decisionmaker are illustrated in Sections 6 and 7 of this report, which also discuss considerations that may be involved in making trade-off decisions. An illustration of the selection of trade-offs to achieve differing objectives (in the context of water supply planning) is included in Milliken and Taylor (in press).

Dominant Approaches

There may be some situations in which one approach can be eliminated from further consideration because it is subordinate to another. Consider, for example, two projects, A and B, that are designed to achieve the same objective (e.g., disposal of wastes). If the net monetary control costs of A exceed those of B and the environmental costs of A clearly exceed those of B (even though the environmental costs are not quantified), then approach B is said to dominate approach A, as A is higher on both types of cost. Hence, assuming that the only factors that enter into the comparison of the two projects are the control costs and the environmental costs, approach A can be discarded. Analysis for dominance can be a useful way of eliminating approaches without needing to fully evaluate some of the costs (Fisher and Peterson, 1976).

Risk Aversion

The role of risk in decisionmaking is discussed in Appendix F. Virtually everyone--firms, the public, decisionmakers, politicians, etc.--is risk averse to some degree. The decisionmaker needs to reflect an appropriate degree of risk aversion in his choice among alternatives. In making this choice, he will generally have to trade-off added costs against reduced probabilities that environmental threats will materialize. The added costs will usually be known with comparative certainty, whereas the threats may be quite ill-defined. An additional complication is that known costs may be borne by one party-at-interest, while the risks may fall on another.

A decisionmaker should remember that if individuals feel threatened, even if the threat does not materialize, then their welfare is reduced (i.e., feeling threatened is a cost). On the other hand, it is probably not reasonable--even if feasible--to achieve a situation that is virtually risk free, since it is likely that in many cases, the marginal cost of risk reduction increases as the level of risk is reduced (Tihansky and Kibby, 1974).

The role of risk aversion and the nature of risk-related decisions in waste management are illustrated in Sections 6 and 7. Though Appendix F contains useful background information on public attitudes toward risk-taking, it does not offer much specific guidance on the degree of risk aversion that should be incorporated into environmental decisions. Hence with the present state of knowledge, selection of an appropriate degree of risk aversion remains the responsibility of the decisionmaker, who must subjectively incorporate public feelings into his judgment.

Equity

Equity is a normative facet of economics. For example, one viewpoint on equity is that potential beneficiaries should pay to obtain that benefit. An alternative approach is that cleanup costs should be borne directly by those who cause the environmental degradation. Yet another view is that unless there are exceptionally powerful arguments in favor of the action it is unreasonable to drastically change business competition by banning (or rendering highly costly) a particular industrial process, for example. These three viewpoints of equity could easily be in conflict, calling for judgment on the equitability of the various outcomes arising from alternative approaches to waste management.

The identification of the parties-at-interest is particularly useful in this respect, as it is comparatively easy to compare the effects of alternative approaches on each of the parties-at-interest. By examining the ways in which costs and impacts fall on different parties-at-interest, the decisionmaker can evaluate the acceptability of the results. He can also devise strategies to render a given approach equitable by finding a way to shift some of the costs and impacts from one party-at-interest to another. For example, examination of the alternatives for the disposal of a particular waste might lead to the conclusion that economic efficiency would be achieved by discharging this waste to a landfill, but that this could render the water unsafe to drink in a limited number of wells. To make this solution equitable, the waste generator could be made to pay for the cost of installing and operating an alternative water supply, possibly together with an additional payment to compensate the well owners for a loss of aesthetic value caused by changing from their well water to the alternative supply.

Summary of the Methodology

The complete procedure involved in defining the scope of the study, applying the analytical framework, and deciding among alternatives is summarized in Table 8.

TABLE 8. SUMMARY OF THE METHODOLOGY

PHASE I. OBTAIN PREREQUISITE INFORMATION

1. Define scope of study;
    a. Geographic area;
    b. Types of wastes;
2. Inventory existing waste situation;
3. Determine how wastes are currently controlled;
4. Ascertain policy objectives.

PHASE II. APPLY ANALYTICAL FRAMEWORK

1. Develop alternative approaches for hazardous waste management. (Consider the status-quo as a base case.)

For each approach under consideration:

2. Allocate wastes to techniques;
3. Develop threat scenarios, list other impacts (resource use);
4. Determine economic and social effects;
5. Determine impacts on the parties-at-interest;
6. Project responses of the parties-at-interest;
7. Predict physical outcomes, including future wastes;
8. Enumerate costs and impacts (discount as appropriate);
9. Reiterate Steps 2 through 8 until results for each approach have been optimized.

PHASE III. MAKE DECISIONS

1. Array alternatives;
2. Eliminate approaches that are dominated by others;
3. Check approaches against policy objectives (e.g., for equity);
4. Examine trade-offs between known costs and threats;
5. Select an approach, using an appropriate level of risk aversion.

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SECTION 6

APPLICATION OF THE METHODOLOGY TO A SINGLE WASTE STREAM

INTRODUCTION

This section provides a simple example of the use of the methodology described in Section 5. This example considers only a single waste stream, and hence much of Phase I of the methodology (obtaining prerequisite information for analysis) is inapplicable, as Phase I is oriented toward complete studies of hazardous waste management within a specified area. The example concentrates on applying the analytical framework (Phase II) and on illustrating the decisionmaking process (Phase III). Though the example is hypothetical, it was inspired by the situation in Oregon analyzed in Section 7. Familiarity with Section 7 is not necessary to follow this section.

THE PROBLEM

An agency responsible for hazardous waste management receives an application from a firm that wishes to dispose of a hazardous waste by deep well injection. The agency has no policy or regulations that specifically ban the use of deep well injection, but any technique used for hazardous waste disposal requires agency approval.

The waste will come from a new process that is assumed to have a 20-year technological life. The process will generate 250,000 m^3 per year of an aqueous waste containing 50 parts per million (ppm) of nondegradable toxic elements (e.g., heavy metals). The firm proposes to dispose of this waste by injecting it into a saline aquifer some 600 m below their premises. They estimate that this will cost them $50,000 per year (including capital charges) over the 20-year life span.

The first step is to investigate the technically feasible alternatives. These are found to be as follows:

1. The waste stream can be reduced to 25,000 m^3 per year with a corresponding increase in the concentration of toxic elements at a cost of $20,000 per year to the firm.

2. The waste stream can be treated to provide an effluent that is acceptable to the municipal sewer. Treatment results in 250 m^3 per year of a toxic sludge. The cost of treatment plus effluent charges would be $115,000 per year.

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3. There are two landfills that could accept either the liquid waste from alternative 1 or the sludge from alternative 2.

The local landfill is a public sanitary landfill located immediately adjacent to a river 50 km from the generating firm. Rainfall in this region is much greater than either open pan evaporation or potential evapotranspiration. This landfill charges \$3.00 per m^3 for any waste.

The secure landfill is a chemical landfill located in a dry zone (rainfall is much less than evaporation or evapotranspiration), 360 km from the generating firm. The gate fee is \$30.00 per m^3 for the sludge and \$20.00 per m^3 for the liquid.

Transportation to either landfill would be by truck, at a cost for either sludge or liquid of \$7.00 per m^3 to the local landfill, and \$22.00 per m^3 to the secure landfill.

4. Other techniques for dealing with the waste (such as resource recovery or ocean dumping) are not feasible.

Hence there are five technically feasible disposal plans, as follows:

A. Deep well injection on the firm's premises.
B. Sludge sent to the local landfill.
C. Concentrated liquid waste sent to the local landfill.
D. Sludge sent to the secure landfill.
E. Concentrated liquid waste sent to the secure landfill.

THREAT SCENARIOS

The next step is to develop likely threat scenarios, at least one for each disposal plan. In-plant accidents under any plan are expected to have approximately similar impacts and hence do not have to be evaluated. The following scenarios represent the major threats identified.

Threat Scenario I: Water Contamination From Deep Well Injection

This scenario applies only to Disposal Plan A. Drinking water is obtained from numerous wells that penetrate a shallow aquifer in the vicinity of the generating firm. This aquifer may become contaminated as a result of some unanticipated interconnection with the deep saline aquifer. The probability of this cannot be determined. If contamination occurs, corrective action could be taken by providing temporary water supplies to the local residents and by drilling several additional wells into the saline aquifer and counterpumping to reverse the migration of the waste. The total cost of this cleanup operation, including some hospitalization costs, is estimated to be some \$2.4 million, which would be considerably less costly than providing a permanent new water supply to the local residents.

Threat Scenario II: Leaching From the Local Landfill

This scenario applies only to Disposal Plans B and C. If the concentrated liquid waste were discharged to the local landfill, it could be assumed that the entire waste would quickly infiltrate the river, because of the wet conditions and absence of leachate barriers at the landfill. If the sludge were deposited at this landfill, an appreciable proportion of the toxic elements would probably be retained, especially in the earlier years; but the above assumption could be used as the worst case. Either sludge or liquid waste contributes 12.5 tonnes of toxic elements per year. The river has a mean flow of 200 m^3/s, implying a toxic element concentration of two parts per billion (ppb) if the waste were uniformly diluted. However, local concentrations are expected to be higher.

The river supports an important salmon fishery, and experts value a typical year's fishing at $800,000, excluding indirect effects such as tourist dollars brought into the region by the fishery. The experts expect the onset of high fish mortality to occur at toxic element concentrations somewhere between 20 and 100 ppb, but they are reluctant to say what impact two ppb would have on the salmon because of the effect variability with duration of exposure, alkalinity, and the presence of other elements. They point out, however, that there is some evidence that fish avoid sublethal concentrations of toxic elements; hence the waste could conceivably ruin the fishery by discouraging the salmon from returning to spawn.

Threat Scenario III: Transport Accidents

This scenario is applicable to Disposal Plans B through E. Statistics indicate that 50 accidents involving waste spills can be expected per billion kilometers traveled by truck in the region. The cleanup cost associated with a typical accident is estimated to be $10,000. Serious injuries and deaths directly attributable to the properties of the waste are expected to be negligible.

Threat Scenario IV: Flash Flood at the Secure Landfill

This scenario is applicable only to Disposal Plans D and E. The most likely threat from the secure landfill is contaminated runoff from a flash flood. Such a flood is expected to occur less than once per hundred years, and damage along the flood path directly attributable to the toxic elements is expected to be minimal. Leaching problems are highly unlikely because of the dry climate and the extreme depth to usable aquifers.

ANALYSIS OF THE ALTERNATIVES

Table 9 presents a comparison of the alternative plans. Only the generator's cost portions of control costs have been evaluated, as other costs are not expected to differ significantly between alternatives. The net present value of the control costs has been calculated by discounting at 10 percent per year. (The Office of Management and Budget recommends the use of 10

TABLE 9. ANALYSIS OF FIVE ALTERNATIVE WASTE DISPOSAL PLANS

	Deep well injection	Local landfill		Secure landfill	
	Plan A	Plan B (sludge)	Plan C (liquid)	Plan D (sludge)	Plan E (liquid)
Control costs:					
Generator's annual costs:					
Onsite operations	$ 50,000	$ 115,000	$ 20,000	$ 115,000	$ 20,000
Transport	--	1,750	175,000	5,500	550,000
Gate fees	--	750	75,000	7,500	500,000
Total	$ 50,000	$ 117,500	$ 270,000	$ 128,000	$1,070,000
Present value of generator's total cost (20 years' cost discounted at 10 percent per year)	$ 426,000	$1,000,300	$2,298,000	$1,089,700	$9,109,500
Other control costs (Administration and monitoring)	ND*	ND	ND	ND	ND
Environmental impacts					
Resource use	ND	ND	ND	ND	ND
In-plant accidents	ND	ND	ND	ND	ND

* Not significantly different.

percent per year as the opportunity cost of capital [Executive Office of the President, 1972].)

As soon as the control costs are evaluated, it is possible to eliminate Plans C and E because these plans are dominated by B and D, respectively. Consider Plan B versus Plan C. The control costs for B are $117,500 per year versus $270,000 per year for C, and detailed evaluation is not necessary to show that the potential environmental damages from B are also less than from C. There is less possibility for release of toxic elements from the sludge (Plan B) than from the concentrated liquid (Plan C); and Plan B requires less transportation than Plan C, which should result in fewer accidents. Thus Plan B is clearly preferable to Plan C as both the quantified costs (the generator's costs) and the nonquantified costs (the potential for environmental damage) are lower for Plan B than Plan C. Similar arguments apply to Plan D versus Plan E. This approach cannot, however, be used to compare Plan A with any other plan, as the environmental threat from Plan A is quite different from those of all other plans. This reduces the number of plans to be evaluated to three (A, B, and D).

The next step is to examine the threats associated with each plan and to determine the nature of the effects of each plan on the parties-at-interest. Table 10 compares the major effects for the three plans. From this analysis the expected attitudes of the parties-at-interest can be projected, and these are also summarized in Table 10.

The parties-at-interest most strongly affected in this example include the water supply authority, and to a lesser extent the water users near the plant, who would be concerned about the threat from deep well injection (Threat Scenario I). Fish experts would oppose Plan B, although fishermen and fish-related industry might perceive only a weak threat. Fishing interests might, however, have an unexpected ally. If Plan A were prohibited, the generating firm itself could well prefer Plan D over Plan B. Though the firm will strongly favor Plan A because of its low cost, the annual cost of Plan D is only $10,500 greater than Plan B, and if the firm opted for B, it would receive adverse publicity if the fish threat (Scenario II) materialized. In contrast, the firm might enhance its reputation as a responsible environmental citizen if it sent its waste to the secure landfill under Plan D. In this case a great deal is at stake (an $800,000 per year fishery and the firm's image) for only a small net benefit ($10,500 per year in reduced costs). Although the probability of the fish threat materializing is unknown, the firm would not have to be very risk averse to prefer Plan D to Plan B. Note that all parties perceive negative impacts for Plan B, which confirms the general unattractiveness of this plan.

DECISIONMAKING

If Plan B is dropped from further consideration, the remaining choice is between Plans A and D and involves reduced control costs and greater damage potential if A is preferred to D. If Plan A is selected, the present value of the control costs discounted over the 20-year project is $663,700 less than for Plan D (i.e., $426,000 versus $1,089,700). On the other hand, Plan A poses the threat of water contamination (Threat Scenario I) with its

TABLE 10. COMPARISON OF THREE SELECTED WASTE DISPOSAL PLANS

	Plan A Deep well injection	Plan B Sludge to local landfill	Plan D Sludge to secure landfill
Present value of generatr's total cost:	$ 426,000	$ 1,000,300	$ 1,089,700
Major threat scenarios:	I: Water supplies contaminated Mitigation cost: $2,400,000, plus cost of changing plan (There is some risk that the mitigation measures might be unsuccessful) Probability: not estimated	II: Salmon fishery at risk Direct value: $800,000 per year Indirect effects locally important Probability: not estimated III. Transport accident Cleanup cost: $10,000 Probability: 2×10^{-5}/year	III: Transport accident Cleanup cost: $10,000 Probability: 1.4×10^{-4}/year IV. Contamination via flash flood Damage potential minimal Probability: 10^{-2}/year
Other economic effects		Product prices slightly higher than with Plan A	Product prices slightly higher than with Plan A
Effect on parties-at-interest*			
Generating firm's management	++	--	-
Local water supply users	-		
Water supply authority	--	-	+
Fish experts	-	--	+
Fishermen, fish-related industry		-	
Environmentalists	--	-	+

* Key to attitudes: ++, favorable; +, somewhat favorable; -, somewhat adverse; --, adverse; (blank), not significant.

cleanup costs and the need to find an alternative waste disposal method if deep well injection does contaminate the water supply. The threats from transport accidents (Scenario III) and from flash floods at the secure landfill (Scenario IV) appear to be so minor that they can be neglected. Nevertheless, it was important to recognize them and demonstrate (or obtain consensus judgment) that they could be disregarded.

If Plan A were adopted, and problems with the deep well scheme developed after five years, the additional costs of taking the corrective action described under Threat Scenario I and switching to Plan D for the next 15 years would have a present value of $1,895,000 when discounted at 10 percent per year. (Note that it was necessary to select a time at which the threat is assumed to materialize in order to be able to calculate a present value.) Thus, assuming that the mitigating measures prove successful and that the data above completely and accurately represent the choice, the economic question becomes: Is it worth risking an unknown probability of future costs that have a present value of $1,895,000 to save certain future costs that have a present value of $663,700? If the decisionmaker disregards equity and is not risk averse, he will favor Plan A when its expected value is lower than that of Plan D. This will occur if the probability of water contamination (Threat Scenario I) is less than 35 percent (i.e., $663,700 ÷ $1,895,000).

A 35 percent probability that contamination will occur seems quite high. There is no known reason why contamination should occur, so on this basis, a decisionmaker who is not unduly risk averse would probably favor the deep well injection plan. However, he must consider some other factors before making a final judgment.

First, there is a slight possiblity that if water contamination occurs, the mitigating measure of drilling additional wells and counterpumping to reverse waste migration might be unsuccessful. In this event, a new water supply would have to be piped in at a cost of tens of millions of dollars. Although this possibility is not formally analyzed, its existence will encourage the decisionmaker to be risk averse.

Second, the decisionmaker should consider equity. If he favors Plan A over Plan D, the waste-generating firm will gain economically, but the local residents will be at risk. However, should the threat of contamination materialize, the water supply authority could bring a suit for damages against the generating firm. Hence although at first sight Plan A is inequitable because benefits and risks accrue to different parties-at-interest, there is a mechanism that might be capable of redressing this inequity. Note that benefits to the firm will ultimately be returned to society through lower prices or higher net income, so a decisionmaker who takes the societal view will not necessarily oppose a plan that benefits a firm while putting the public at risk.

Finally, the decisionmaker must consider the less tangible factors. Are the local residents and environmentalists highly disturbed about the waste injection proposal? If so, they will be subjected to psychological damages not accounted for in the dollar costs discussed above. How important is the

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option value associated with not contaminating the saline aquifer? Are there any other factors that have not been considered? Public hearings could be used to gauge the strength of local feelings and concerns.

Even if a decisionmaker does not consider the personal risk of making a choice that is later perceived to be a poor one, the issues are complex. Excessive risk aversion will reduce society's welfare just as excessive risk proneness will. Each decisionmaker must formulate his own trade-offs among the various factors. However, it is hoped that by systematically laying out and analyzing the principal features involved in the alternatives, the decisionmaker's task can be made easier. He must, however, still make the decision.

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SECTION 7

CASE STUDY OF HAZARDOUS WASTE MANAGEMENT IN OREGON

INTRODUCTION

Rationale Behind the Choice of Oregon

The methodology described earlier could be applied to several categories of problems. Those considered for a case study included:

1. A study of a complete local or regional situation;
2. Analysis oriented toward a specific industry;
3. A study of a specific material that may be present in hazardous wastes;
4. A study of a specific means of disposal and alternatives to this.

The topic chosen was a study of alternatives for hazardous waste management in the State of Oregon. There were two principal reasons for this choice. First, EPA suggested that the methodology be demonstrated by application to a State, as this would be most useful when the RCRA was implemented. Second, Oregon had good information on hazardous waste generated and disposed of in the State, which provided the necessary data base. In addition, the hazardous waste situation in Oregon is not so complex as to present an intractable example, but the presence of some regional wastes and climatic differences within the State provide an interesting analysis.

Some Characteristics of Oregon

Oregon has a total area of 251,000 km^2, and divides naturally into three major parts separated by two mountain ranges. The coastal area is separated from the Willamette Valley and southwestern valleys (of the Rogue and Klamath Rivers) by the Coast Range, while the High Plateau of eastern Oregon is separated from the Willamette Valley and the southwestern valleys by the Cascade Mountains (see Figure 8). The coastal area and Coast Range are comparatively wet (e.g., 150 to 255 cm of precipitation per year), while much of the Willamette Valley and southwestern valleys receive 102 cm per year or less. Beyond the Cascades, most of eastern Oregon is dry, with large areas averaging less than 30 cm per year (Sternes, 1967).

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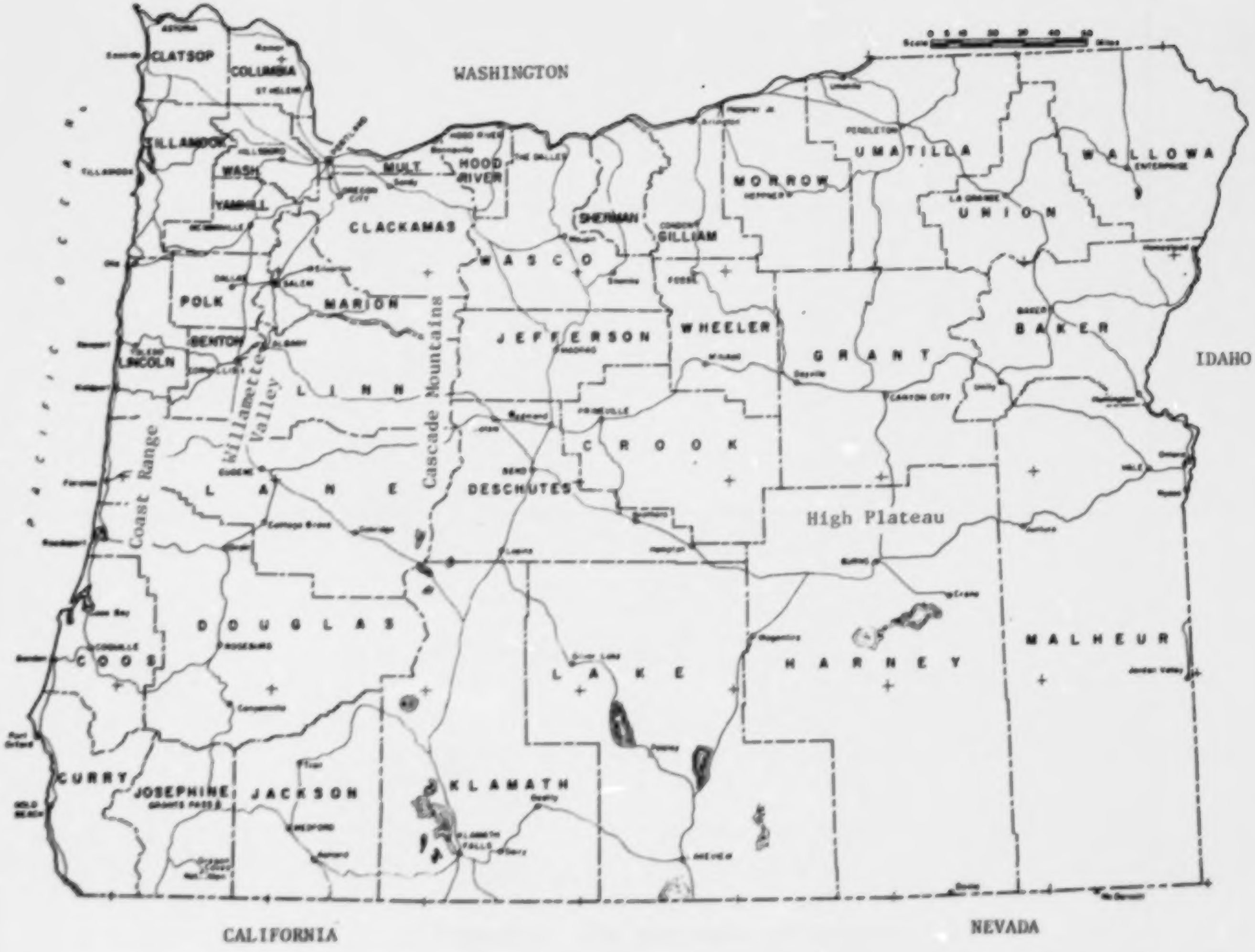
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MARION
BENTON
LINCOLN
LINN
LANE
DOUGLAS
COOS
CURRY
JOSEPHINE
JACKSON
KLAMATH
LAKE
DESCHUTES
CROOK
JEFFERSON
WASCO
SHERMAN
GILLIAM
WHEELER
MORROW
UMATILLA
UNION
WALLOWA
BAKER
GRANT
HARNEY
MALHEUR
Coast Range
Willamette Valley
Cascade Mountains
High Plateau
ASTORIA
ST HELENS
PENDLETON
CANYON CITY
ENTERPRISE
Scale
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Figure 8. The geography of Oregon

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In 1975, Oregon's population was approximately 2.28 million persons. Much of the State's population lives in the Willamette Valley, including the Standard Metropolitan Statistical Areas (SMSA's) of Eugene-Springfield and Salem, together with the Portland metropolitan area, which is at the confluence of the Willamette and Columbia Rivers. The 1975 population of Oregon's portion of the Portland SMSA was 0.94 million, and the State total for the three SMSA's was 1.38 million (U.S. Department of Commerce, 1977). Most of the remainder of the population lives along the coast, along the Columbia River, and in the southwestern valleys. Industrial (manufacturing) activity largely correlates with population, being particularly strong in the Willamette Valley.

The main communication routes are east-west along the Columbia River, which forms much of the State's northern boundary, and north-south along the Willamette River and southwestern valleys. The distribution of population and the transport corridors results in the economic isolation of Oregon from the adjacent States of Idaho and Nevada, and in part from California. However, there is substantial interaction with the State of Washington, as the Willamette Valley transport corridor extends north in Washington to the Seattle area, and Vancouver (Washington) is the major city immediately across the Columbia River from Portland.

The 1970 census of population revealed that civilian employment in Oregon totaled 788,500, or 37.7 percent of the population, distributed by industry as shown in Table 11.

TABLE 11. EMPLOYMENT BY INDUSTRY IN OREGON AND THE UNITED STATES*

Industry	Percent of total employment	
	Oregon	United States
Agriculture, forestry & fisheries	5.3	3.5
Mining	0.2	0.8
Construction	5.4	5.5
Manufacturing	20.4	24.4
Transportation, communications & other public utilities	6.8	6.4
Wholesale & retail trade	20.9	18.9
Various services	36.1	34.4
Industry not reported	4.9	6.1
	100.0	100.0

* Source: U.S. Department of Commerce, Bureau of the Census, 1973. (Data relate to employed persons aged 14 years and over.)

If employment for Oregon is compared to that for the entire United States, it will be seen that Oregon has a lower proportion of its work force engaged in manufacturing and mining, a significantly higher proportion in agriculture, forestry, and fisheries, and somewhat more in trade and services.

The methodology described in Section 5 will now be applied to a study of hazardous waste management alternatives in Oregon, insofar as possible following the procedure outlined in Table 8.

Hazardous Wastes in Oregon

Three major sources of data about hazardous wastes in Oregon were available: A survey conducted by the Oregon Department of Environmental Quality (DEQ) in 1972 and 1973, a study conducted by Battelle Memorial Institute, Pacific Northwest Laboratories (Battelle) in 1975, and data on wastes actually shipped to a chemical waste disposal facility near Arlington, Oregon.

The survey conducted by the Oregon DEQ (State of Oregon, 1974) identified major Oregon producers of wastes that were subjectively judged to be potentially hazardous. Total hazardous waste generation in Oregon was in most cases estimated by extrapolation on the basis of employment in each industrial category.

The study conducted by Battelle (Stradley, Dawson, and Cone, 1975) endeavored to identify all significant generators of hazardous wastes within EPA Region X (Oregon, Washington, Idaho, and Alaska). As far as possible, this study used the Battelle hazardous waste decision model (see Figure 2) or the inclusion of a waste component on the EPA proposed list of nonremovable hazardous substances (U.S. Environmental Protection Agency, 1974a) as its criteria for identifying hazardous wastes.

Data were available on wastes actually shipped to the secure disposal facility operated by Chem Nuclear Systems, Inc., near Arlington, Oregon. (Arlington is located in Gilliam County, adjacent to the Columbia River--see Figure 8.) This facility, which includes a chemical landfill and neutralization/evaporation lagoons, commenced regular operation in May 1976 and is currently the only chemical landfill in Oregon. Its geographic location is such that it is likely to receive almost all the Oregon-generated wastes that are disposed of in a secure disposal facility. For the period covered by the data used in this study (1975-77), the only categories of nonradioactive hazardous waste that were legally required to be disposed of at a chemical landfill were pesticide wastes and PCB's.* Hence most Oregon-originated wastes that were sent to Arlington were not specifically required to be disposed of in that way. However, all wastes that are sent to Arlington are subject to Oregon DEQ permit.

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* The Oregon statutes that related to "environmentally hazardous wastes" (Oregon Revised Statutes [ORS] 459.410-459.690, first enacted in 1971) required such wastes to be designated by the Oregon DEQ. Until May 1979, only waste pesticides, pesticide manufacturing residues, and PCB's had been so designated. (Personal and telephone interviews, F. Bromfeld, Oregon DEQ, Portland, Oregon, March 9, 1977; April 17, 1979.) Subsequently, in May 1979, the Oregon Environmental Quality Commission adopted a comprehensive set of criteria for establishing wastes as hazardous (Oregon Administrative Rules [OAR] 63-100 to 63-135).

PREREQUISITE INFORMATION AND DECISIONS

Scope of the Study

Geographic Area--

The geographic area of the case study was taken as the State of Oregon. This choice is convenient because the State is a complete political unit and because its industrialized area (the Willamette Valley) is isolated from the industrialized areas of all adjacent States except Washington.

Types of Wastes--

Industrial process wastes were the primary category considered, but waste laboratory chemicals and unwanted pesticides were also included. The case study excluded radioactive wastes, mining wastes, pesticide containers, and hospital wastes. Apart from the possibility of some reactive (explosive) wastes at the Umatilla Army Depot (these wastes would not fall under DEQ control) no special wastes were known to exist in the area.

Inventory of Existing Waste Situation

Quantities and Types of Wastes Generated--

Table 12 presents data derived from the Battelle study (Stradley, Dawson, and Cone, 1975). The data, which were collected in mid-1975, were believed by the authors of that study to amount virtually to a census of all potential hazardous waste generators in Oregon. (Personal interview, G. Dawson and J. McNeese, Battelle Memorial Institute, Pacific Northwest Laboratories, Richland, Washington, April 26, 1977.) The data took account of the earlier survey by the Oregon DEQ (State of Oregon, 1974). However, the data in Table 12 cannot be compared directly with those published by Stradley, Dawson, and Cone (1975) because of slightly differing coverages (e.g., wastes recycled within a plant were excluded from Table 12). Since then, in 1978-79, the Oregon DEQ has conducted another survey, but the results of that survey were not available in time to be used in this case study.

In Table 12, hazardous wastes have been divided by the author into five categories: Pesticides, heavy metals, solvents and oils, phenols, and other chemicals. In practice, a given waste often fell into more than one of these categories. When this occurred, the waste was attributed to the first category that was represented by more than trace quantities. The sequence is intended to be crudely hierarchial in terms of the threat or potential for damage that the waste category is capable of causing. Clearly, even if only intrinsic factors (i.e., the hazardous properties of the waste itself, not the potential magnitude of effects) are considered, a rigorous hierachy cannot be established, as this would depend on the actual materials involved and their concentrations. This is particularly true for the catch-all category of "other chemicals," although the bulk of this material does not appear to be very hazardous. Much of this material arises from the primary aluminum manufacturing industry and is spent potliners (carbon) contaminated with fluoride and cyanide, and a calcium fluoride sludge. Most of the rest is lime sludge.

TABLE 12. GENERATION AND DISPOSAL OF POTENTIALLY HAZARDOUS WASTES IN OREGON*†

	Amount of waste (m^3 per year)					
Item	Pesticides	Heavy metals	Solvents and oils	Phenols	Other chemicals	Total
Waste generated by industrial category:						
Pesticides and wood treating	995	-	-	-	-	995
Resin & glue	-	-	26	1,112	-	1,138
Paints & inks	-	-	113	-	42	155
Other chemicals	-	-	474	-	1,312	1,786
Batteries (lead-acid)	-	109	-	-	-	109
Electroplating	-	74	-	-	-	74
Electronics, etc.	-	1,723	2	-	-	1,725
Metals manufacture	-	517	-	-	10,796	11,313
Miscellaneous	-	155	143	-	4	302
Total	995	2,578	758	1,112	12,154	17,597
Waste disposed by method:						
Onsite						
Landfill	-	1,310	-	34	1	1,345
Storage	23	464	24	358	2,307	3,176
Lagoon	492	22	-	10	4,149	4,673
Sewer	-	7	-	-	2	9
Local landfill	-	78	20	-	33	131
Secure disposal (chemical landfill)	441	-	-	20	-	461
Resource recovery	-	622	669	690	5,652	7,633
Hauler/unknown	39	75	45	-	10	169
Total	995	2,578	758	1,112	12,154	17,597

* Source: Adapted from Stradley, Dawson, and Cone, 1975 (including unpublished data sheets prepared in conjunction with the report).

† These data were developed using criteria for hazard potential different from those employed by the Oregon DEQ. Only wastes generated on a regular basis are included.

Industries have been grouped into nine categories in Table 12, partly on the basis of the types of wastes generated, and partly on the basis of industrial similarity. The first two categories, pesticide manufacture and wood treating, and resin and glue manufacture, were chosen to include all regular generators of waste pesticides and phenols, respectively. In addition to the categories of wastes listed above, small quantities of PCB's require disposal, but as they are not generated on a regular basis they were excluded from Table 12. Oregon regulations require that small quantities of PCB's and contained PCB's be disposed of in a chemical landfill, i.e., at the Arlington disposal facility, whereas bulk PCB's are currently being stored (for eventual incineration) or sent out of state. (Telephone interview, F. Blomfeld, Oregon DEQ, Portland, Oregon, August 23, 1979.)

Table 12 also shows the 1975 disposition of these wastes. Wastes that were recycled within a plant have been excluded, as well as regular effluents legitimately discharged under the National Pollutant Discharge Elimination System (NPDES) or the sewer regulations in effect at the time of the study. There was no deep well injection or ocean dumping. Note that a comparatively high proportion of the wastes (43 percent) was being subjected to resource recovery. Two main factors account for this. First, over half this material was spent potlinings sent from an Oregon aluminum plant to a plant in Washington (operated by the same company) for cryolite recovery. Even if this major waste stream is subtracted, 20 percent of all Oregon hazardous waste (originating from 32 firms) was still being sent for resource recovery.

The relatively high proportion of resource-recovered wastes (although not strictly comparable, the U.S. proportion is 1.7 percent [U.S. Environmental Protection Agency, 1977b]) appears to relate to the presence of a resource recovery infrastructure in the Pacific Northwest. This in part probably reflects the ecological consciousness of the area. In 1975-77, Oregon had an oil re-refiner in Portland and three solvent reclaimers (two in Portland, and one in Eugene), plus a number of wax recyclers in Portland. Although there was no longer a secondary lead smelter in Oregon (the nearest was in Seattle, Washington), there was one Portland firm specializing in lead recovery, primarily serving the lead-acid battery manufacturers. Perhaps more significantly, however, there were two specialist resource recovery firms in Seattle, Washington, that accepted a wide variety of materials for processing (Stradley, Dawson, and Cone, 1975). In addition to materials that are frequently reclaimed (such as solvents), these firms have found uses for wastes that generally are not considered attractive candidates for resource recovery, such as certain metal finishing wastes (see Battelle-Columbus Laboratories, 1976; Crumpler, 1977).

Table 12 shows that only 461 m^3 per year of wastes were being sent for secure disposal. At the time that these data were collected, there were no chemical landfills operating in either Oregon or Washington. The nearest secure disposal site was the Wes Con, Inc., facility at Grand View in southwestern Idaho, some 740 km from Portland. This site provides permanent storage of wastes in abandoned missile silos (see Ghassemi and Quinlivan, 1975). Since that time, Chem Nuclear Systems, Inc., opened their secure disposal facility near Arlington, Oregon, about 225 km by road from Portland. Consequently, it is not surprising that by 1977 greater quantities were being sent to Arlington. The permit data have enabled one-shot shipments to

Arlington to be separated from recurring shipments. Permit data show that recurring wastes from Oregon are expected to total 6,450 m³ per year, broken down as follows:

Pesticides	1,047
Heavy metals	1,148
Solvents and oils.	422
Phenols.	1,679
Other chemicals.	2,154

The actual total for September 1976 through August 1977 was 3,687 m³ (one-shot shipments for this period were 285 m³). The Arlington site commenced regular operation in May 1976, and the period September 1976 through August 1977 was the latest full year for which data were available when this analysis was conducted. Elimination of data from the first few months of operation should have reduced the impact of wastes being taken from storage.

One feature of particular interest is that the recurring wastes to be shipped to Arlington are produced by 38 firms, only 15 of which were identified by Battelle as producing hazardous wastes. (These 15 firms do, however, generate the bulk of the recurring wastes that are being shipped to Arlington; permit data show that they expect to produce 4,474 m³ per year.) This apparent discrepancy may be in part attributed to hazardous waste classification criteria. In some cases a waste that is being sent to Arlington may have been classified as nonhazardous by Battelle. On the other hand, several of the firms involved were from SIC categories that might not be expected to produce hazardous wastes (e.g., a manufacturer of fireplaces).

Any comparison of the permit data with the shipments data must be made with caution, because of the comparatively short period involved (one year) and the fact that some of the permits were issued during the period for which the data were collected. Analysis of data on a permit-by-permit basis showed that though some of the permit quantity projections were accurately realized, in several cases there were discrepancies as large as a factor of two in either direction, while in a few cases the discrepancies were much larger. On the other hand, the permit quantities tended to be larger (often by a factor of two to four) than the Battelle data for the same waste stream. No shipments had been received from nine firms expecting to produce 919 m³ per year. In the case of one major stream of waste acid, this was probably because of the use of an alternative method of disposal; in some of the others it may have been that the quantities of wastes that had accrued were comparatively small and had yet to be shipped.

Statistics on Firms Generating Hazardous Wastes--

Table 13 provides some data on the number of firms identified by Battelle as generating hazardous or probably hazardous wastes. The industry categories are the same as those used in Table 12, and Table 13 lists the SIC's of the firms identified by Battelle. Of the 94 firms, six electroplaters did not generate a hazardous waste as such but had hazardous elements in their effluents. Increasingly stringent sewer regulations are expected to force these firms and some others to treat their effluents, resulting in additional heavy metals sludges. The quantities in Table 12 only reflect

TABLE 13. OREGON FIRMS THAT MAY GENERATE HAZARDOUS WASTES

Industrial category	SIC's included[a]	No. of firms identified by Battelle study[b]	No. of firms in *Directory of Oregon Manufacturers*[c]
Pesticides and wood treating	2491, 2879	9	16
Resin and glue manufacturers	2821, 2865 2869, 2891	8	17
Paints and inks	2851, 2893	14	23
Other chemicals	2813, 2818 2892, 2992	6	5
Batteries	3691	9	8
Electroplating	3471	18[d]	27
Electronics, etc.	3661, 3679 3825	4	17
Metals manufacturers	3312, 3324 3334, 3339 3341, 3361 3398	8	27
Miscellaneous	2231, 2253 2711, 3111 3231, 3412 3425, 3429 3433, 3479 3482, 3612 3629, 3743 9711	18	197
Total		94	337
Total, excluding miscellaneous		76	140

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[a] SIC's of firms included in Table 12 that generate potentially hazardous wastes.

[b] Based on Stradley, Dawson, and Cone, 1975 (including unpublished data sheets prepared in conjunction with the report).

[c] Number of firms having listed SIC(s) as primary SIC in *Directory of Oregon Manufacturers* (State of Oregon, Department of Economic Development, 1976).

[d] Twelve firms generate hazardous wastes, but an additional six firms have hazardous elements in their effluents (see text).

data from 68 firms. Twenty additional firms generated hazardous wastes, but the amounts were not determined. However, in most cases the quantity is thought to be small, and hence inclusion of these missing data would probably not cause major changes in Table 12. The magnitudes of the wastes (excluding effluents) from the 68 firms form a typical Pareto distribution, as follows: The five largest generators produce 75 percent of the waste, the 10 largest generators produce 89 percent of the waste, and the 20 largest generators produce 97 percent of the waste. (Note that a firm may have more than one waste stream.) Of course these quantities give little indication of the damage potential of these wastes, but the data do suggest that it may be reasonable to simplify analysis by concentrating on the larger waste streams.

Table 13 shows that if the numbers of firms identified by Battelle as generating potentially hazardous wastes are compared to the total numbers of firms in the same SIC designations, in most cases there are significantly more firms in Oregon than those identified by Battelle. In many cases this may reflect differences in manufacturing processes, but it could also be that the smaller firms are more reluctant to admit that they generate hazardous wastes. In the case of the "miscellaneous" category, the huge difference in figures is largely accounted for by SIC 2711 (Newspapers: Publishing, Publishing and Printing), as Battelle only identified one generator of hazardous waste from a total of 123 firms.

It is interesting to note that of the 14 broad categories of industry identified by EPA as generating most of the potentially hazardous waste in the United States (U.S. Environmental Protection Agency, 1977b, see Table 3), only petroleum refining (SIC 2911) is absent from Table 13. Naturally however, the relative proportions of these industries do not mirror the aggregate of the United States and not all the subcategories of the 14 major categories are represented.

The geographic distribution of the firms listed in Table 13 is as follows:

Portland SMSA (Oregon counties only).	66
Remaining Willamette Valley	19
Coos County (coast)	1
Jackson and Josephine Counties (south). . . .	5
Eastern Oregon.	3
Total.	94

These data confirm the importance of the greater Portland area and the Willamette Valley as the industrial areas of Oregon. They also simplify the analysis, since there is only one large-scale generator of hazardous waste (an aluminum plant in Wasco County) outside the Willamette Valley.

Future Waste Generation--

At this stage, a preliminary estimate of future changes in hazardous waste generation can be made (this estimate may require modification after the approaches to hazardous waste management have been selected). Heavy metals wastes are expected to increase from 2,578 m^3 to about 3,600 m^3 per year, partly because of increasingly stringent sewer regulations. (Estimate by L.W. Ross, Denver Research Institute, Denver, Colorado, based on analysis of effluent data and chemicals used by the waste generating firms.) Otherwise, substantial increases do not seem particularly likely. The largest generator of hazardous wastes in Oregon, the primary aluminum industry, is unlikely to expand its activities in the region because its economics are being unfavorably affected by the loss of low-cost power. Oregon generally tends to attract clean industries that generate comparatively small quantities of hazardous wastes (e.g., electronics). In cases where new plants have replaced older ones, waste generation has frequently been reduced. The finding that for several industrial sectors, hazardous waste generation in Oregon appeared to have decreased between studies in 1972/73 (State of Oregon, 1974) and 1975 (Stradley, Dawson, and Cone, 1975) tends to support the view that waste generation is unlikely to exhibit substantial growth in the future.

This conclusion is reinforced by examining the national projections of hazardous waste generation for the 14 major industrial groups shown in Table 3, only three of which are projected to have aggregate increases in hazardous waste generation that exceed 100 percent between 1974 and 1983. The three industrial groups with large increases are battery manufacture (2,000 percent increase in hazardous wastes), textile dyeing and finishing (373 percent increase) and waste oil re-refining (253 percent increase). Increases in hazardous wastes from the battery industry appear to stem from enhanced water pollution controls. (Note that the consultants' figures on hazardous waste generation from battery manufacture [McCandless et al., 1975] and textile dyeing and finishing [Abrams, Guinan, and Derkics, 1976] are higher than those of EPA used in Table 3 [U.S. Environmental Protection Agency, 1977b], possibly because the Agency may have reclassified some waste streams as nonhazardous.) For Oregon an increase in hazardous waste from the battery industry has been incorporated in the estimate of increased heavy metals wastes. (This estimate assumes that there is no major change in the structure of the industry.) In the case of firms involved in textile dyeing and finishing, the Battelle data show only very small quantities of potentially hazardous wastes being generated, so a significant increase (in absolute terms) in the wastes from this Oregon industry seems unlikely. For waste oil re-refining, the increase is expected to stem largely from increased production, with newer plants replacing many of the old ones (Swain, 1976). Oregon's oil re-refiner produces comparatively small quantities of hazardous wastes, and so speculation as to the future of this industry in Oregon would not be very important.

On the other hand, the Oregon DEQ took a subset of the industry categories investigated in 1972 and reevaluated their waste generation in 1978. For these industries, wastes that might be hazardous increased 105 percent, from approximately 11,300 to 23,200 m^3. (Telephone interview, F. Bromfeld, Oregon DEQ, Portland, Oregon, April 17, 1979.) These data may be misleading, however. At the time of the first DEQ survey (and also the Battelle survey), there was no chemical landfill in Oregon, and only pesticide wastes were required by law to be disposed of (in Oregon) in a secure disposal site. Out-of-state disposal alternatives were unattractive (see Stradley, Dawson, and Cone, 1975) and hence the generators had an incentive to minimize the quantities of wastes actually generated, or at least the quantities to which they admitted. In contrast, there is an incentive to the generators to overstate the quantities on the DEQ permit applications, since they would need to reapply if the quantity was found to have been significantly understated. This effect may have carried over to the DEQ survey in 1978, giving rise to the apparent increase. A second factor that may have resulted in increased quantity estimates is the more extensive use of offsite disposal (e.g., sending a waste to Arlington, as opposed to storing or disposing of it onsite). Where disposal took place on a firm's premises, the firm may not have been particularly well aware of the quantities of wastes actually generated, whereas when a waste is shipped offsite, the firm would become much more conscious of the quantities involved.

Control of Hazardous Wastes in Oregon

Oregon first enacted a statute to control hazardous wastes in 1971 (ORS 459.410 through 459.690). The effect of the statute was to designate waste pesticides and pesticide manufacturing residues as "environmentally hazardous wastes," and to make provision for industrial process wastes to be classified as hazardous by the Environmental Quality Commission after notice and public hearings (ORS 459.410). In 1977, PCB's were also designated as hazardous, but no other process wastes were classified as hazardous under this scheme until 1979. Oregon law prohibits the disposal of a hazardous waste within the State, except at a licensed hazardous waste disposal site (ORS 459.510). The Arlington chemical landfill is the only licensed site in Oregon, and as already mentioned, it is believed to receive virtually all of Oregon's hazardous wastes that are sent for secure disposal. Very small quantities of Oregon wastes are disposed of in Wes Con's facility in Idaho, and Arlington receives substantial quantities of wastes from Washington and occasional wastes from British Columbia. (Personal interview, F. Bromfeld, Oregon DEQ, Portland, Oregon, March 9, 1977.) Officials have no knowledge of any regular hazardous waste movements between Oregon and California (Personal communication, D. Storm, California Department of Health, Berkeley, California, September 19, 1977), and because of the location of the Oregon hazardous waste generators there is no reason to expect Oregon wastes to be disposed of in Nevada.

Under the pre-1979 rules, all wastes not designated or officially classified as hazardous were controlled by indirect methods. Industrial wastes are not officially allowed to be disposed of in sanitary landfills without DEQ permission. The DEQ normally refused permission to dispose of heavy metals and highly oily wastes in sanitary landfills. However, some marginal industrial wastes from the greater Portland area were channeled to the city's St. Johns landfill adjacent to the Columbia Slough in Portland. (Personal interview, C. Gray, Oregon DEQ, Portland, Oregon, March 11, 1977.) Some industrial wastes originating outside the Portland area went to other public landfills. (Personal interview, W. Dana, Oregon DEQ, Portland, Oregon, April 17, 1977.) It was generally felt that industry had cooperated well by, for example, storing materials while awaiting a suitable method of resource recovery, treatment, or disposal, and by sending some wastes that were not really hazardous to the Arlington secure disposal facility.

Policy Objectives

The Oregon DEQ has established objectives (State of Oregon, Department of Environmental Quality, 1978) for its solid waste program (which includes hazardous waste management), as follows:

1. To minimize the generation of and maximize recovery of resources from solid waste;
2. To provide for environmentally acceptable collection, transport, storage, treatment, and disposal of solid waste;
3. To develop positive public attitudes, awareness, and actions that maximize citizen involvement in solid waste management;
4. To develop and implement a continuing process for solid waste management planning;
5. To maximize the effectiveness of agency resources to accomplish solid waste management programs;
6. To achieve a reasonable balance between environment, energy, natural resources, and economic considerations.

These general objectives are supplemented by specific goals, such as one for 1979, which was to increase the annual amount of industrial hazardous waste recycled or recovered by 100 percent over that of 1977. None of the specific goals addresses objective 6, which calls for the most difficult decisions from the planning viewpoint.

APPLICATION OF ANALYTICAL FRAMEWORK

Development of Alternative Approaches for Hazardous Waste Management

Before discussing possible approaches to hazardous waste management in Oregon, a major caveat is necessary. The discussion of hazardous waste management alternatives in this chapter must not be taken to imply that the alternatives would be legal under either Oregon law or the provisions of the RCRA (PL 94-580). The analysis is presented both to illustrate the methodology and to demonstrate what might be involved if different approaches were employed. Discussion of an approach does not constitute an endorsement of that approach--as already stressed, this is the prerogative of the appropriate decisionmakers. Furthermore, a far more detailed analysis than that presented here would be necessary to develop a complete hazardous waste management policy for Oregon.

Figure 9 provides an overview of four possible approaches to hazardous waste management in Oregon and links these approaches to the waste management techniques that may be involved. The four approaches are arranged, from top to bottom, in increasing comprehensiveness and complexity of regulation. Depending on precisely how the approaches are specified, this could also correspond to an increasing degree of risk aversion on a decisionmaker's part, or to increasing anticipated environmental quality.

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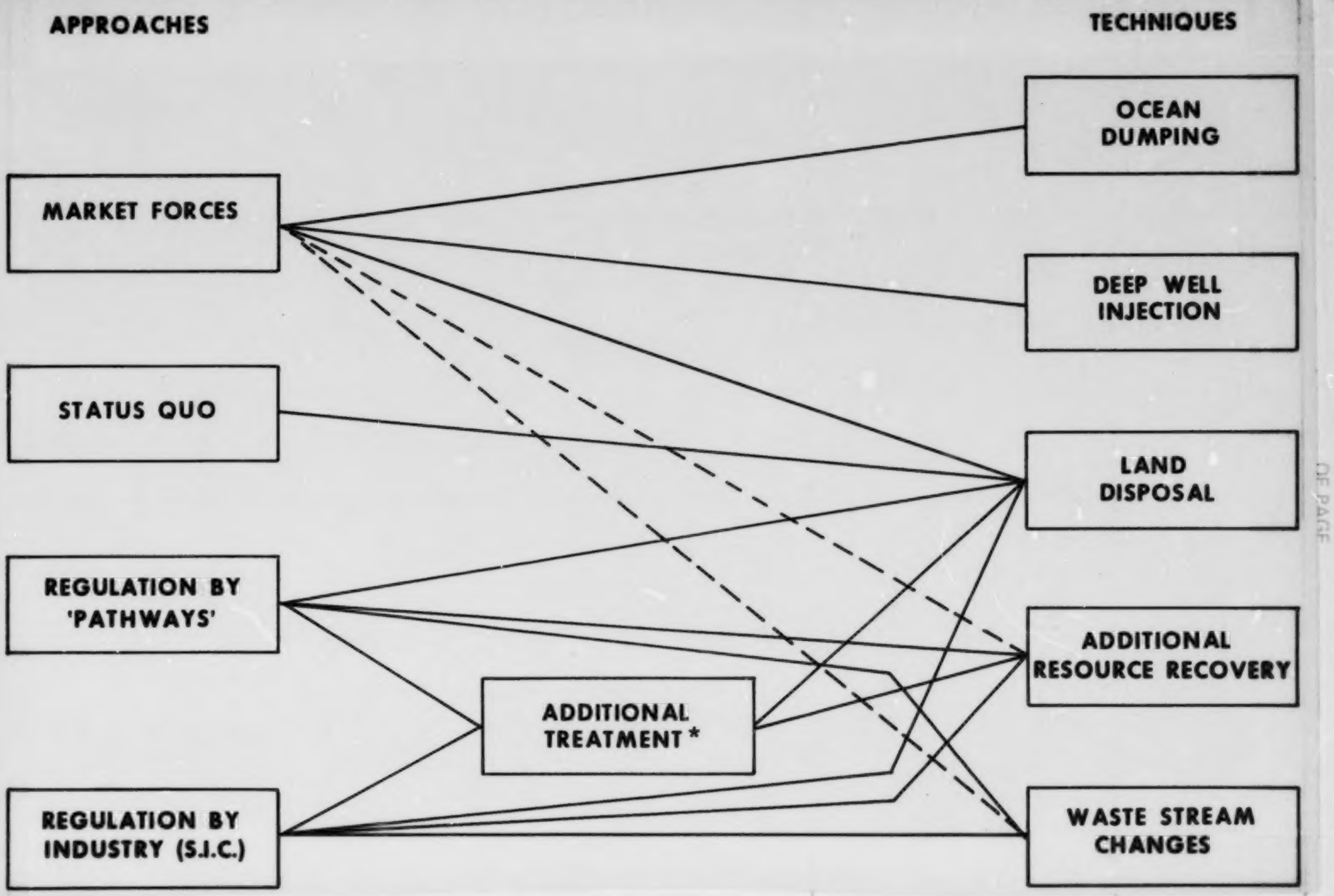
APPROACHES
TECHNIQUES
MARKET FORCES
STATUS QUO
REGULATION BY 'PATHWAYS'
REGULATION BY INDUSTRY (S.I.C.)
ADDITIONAL TREATMENT *
OCEAN DUMPING
DEEP WELL INJECTION
LAND DISPOSAL
ADDITIONAL RESOURCE RECOVERY
WASTE STREAM CHANGES

* Treatment includes incineration.

Figure 9. Approaches for hazardous waste management in Oregon.

The market-forces approach would essentially allow waste generators to decide what to do with their wastes. This would open up the possibilities of ocean dumping and deep well injection and might cause changes in waste streams and resource recovery (the latter relationships are shown dashed in Figure 9).

The status-quo approach, i.e., continuation of the pre-1979 approach to hazardous waste management in Oregon, is used as a base case. The emphasis in the status-quo approach is on responsible land disposal.

The status-quo describes the situation in Oregon in 1977, and uses 1975-77 data. At that time, hazardous waste management in Oregon was in transition from a form of market-forces approach toward regulation by pathways. When the May 1979 rules are fully implemented, Oregon will be using a regulation-by-pathways approach, but this approach will not be identical to the regulation-by-pathways approach considered in this study.

The approach of regulation-by-pathways is intended to correspond to the approach that EPA is adopting under the RCRA. The concept is to control rigorously the paths that the wastes can take, but not to mandate any special forms of treatment technology, etc. The general effect of this approach would be to enhance the security of land disposal with respect to the status-quo. Economic forces could tend to cause changes in waste streams and increase resource recovery.

If wastes were subject to regulation-by-industry (SIC), it could involve specifying the control or treatment technology, and/or the means of disposal for each industrial category. This approach could be arranged to give a higher or lower expected level of environmental quality than regulation-by-pathways, depending on the levels of treatment required and the wastes encompassed. However, as will be shown, it is the most complex in terms of the degree of regulation.

In the analysis that follows (i.e., Steps 2 through 8 in the Application of the Analytical Framework phase of the methodology outlined in Section 5--see Table 8), the market-forces and the regulation-by-pathways approaches will be discussed together and compared with the status-quo approach. The regulation-by-industry (SIC) approach is quite different and will be treated separately following the other cases.

Allocation of Wastes to Techniques

Status-Quo Approach--

Although Table 12 provides one set of data on hazardous waste generation in Oregon, as already indicated there are other conflicting data on quantities and disposal methods. In addition, even under the status-quo approach, future waste streams will differ, because of increasing stringency of sewer and NPDES discharge regulations, opening of new firms and closing of old ones, and process changes. For these reasons, projected data on the status-quo approach, given in Table 14, will be used for the evaluation. These data in part reflect the larger quantities (compared to the Battelle data) permitted for disposal at Arlington. However, allowance has been made

TABLE 14. PROJECTED DATA ON FUTURE HAZARDOUS WASTE GENERATION IN OREGON UNDER THE STATUS-QUO APPROACH*

	Cubic Meters Per Year					
Disposition	Pesticides	Heavy metals	Solvents and oils	Phenols	Other chemicals	Total
Onsite landfill	-	1,800	-	300	2,300	4,400
Onsite lagoon	500	-	-	200	200	900
Local landfill	-	200	100	-	100	400
Secure disposal†	600	1,000	300	1,500	1,500	4,900
Resource recovery	-	600	700	700	5,600	6,900
Total	1,100	3,600	1,100	2,000	9,700	17,500

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* Source: Author's estimates, based on all available data. Data are applicable to the eary 1980's, see text. (Note that criteria for designating waste as hazardous are not the same as those that would be applied under 1979 Oregon law.)

† At Arlington waste disposal site.

for overstatement of quantities on the permit applications, and it has also been assumed that some of these materials would not qualify as hazardous under the Battelle hazardous waste decision model and should therefore be excluded. The data reflect the author's views on the likely disposition of the anticipated increase in heavy metals wastes, and they allow for the planned elimination of the large quantity of fluoride-bearing sludge that is presently lagooned. In addition, the data have been simplified by disregarding minor combinations of waste type and disposition. Since potentially hazardous waste volumes are expected to remain more or less static once the effect of more stringent sewer (and NPDES) regulations have taken effect, no specific year has been associated with Table 14. The data should be most realistic in the early 1980's.

The simplification of data required to project Table 14 should not be regarded as a drastic step. Policy development and analysis should not be allowed to be unduly sensitive to basic assumptions, unless these are exceptionally well established. Hence it is perfectly appropriate to work with approximate or simplified data and to test the sensitivity of policy implications to these data assumptions.

Market-Forces Approach--

It will be assumed that pesticide wastes continue to be disposed of at a chemical landfill, except for some very dilute wastes (wash waters) that are lagooned. Battelle only identified one waste stream of significant size in this category. The waste is so dilute that it is not considered to constitute a significant hazard, and for this reason the Oregon DEQ has not required that it be sent to Arlington. (Telephone interview, E. Chiong, Oregon DEQ, Portland, Oregon, June 5, 1979.) (For pesticide wastes this represents no change from the status-quo approach.)

Possibilities for ocean disposal--In terms of cost, barge disposal might be an attractive proposition for high-volume wastes from the greater Portland area or along the Columbia River. Mixing of lower volume wastes from different sources to provide full loads could be dangerous and has not been considered. The smallest sized barge used for bulk ocean dumping has a capacity of about 900 tonnes (Smith and Brown, 1971). There appear to be no more than four nonsolid hazardous waste streams that exceed this quantity in a year and although they all originate from the greater Portland area, the total annual volume (3,800 m^3 or approximately 4,800 tonnes) would almost undoubtedly be too small (even if a few other waste generators joined in) to support the operation of a specially constructed disposal barge during even a part of the year. Furthermore, three of these wastes are comparatively dense sludges that could make disposal from tank barges difficult if not impossible. It would probably be some 200 km to the nearest feasible dumping ground in the Pacific Ocean, which would likely place the cost at the high end of the usual range (see Table C-1). Under the status-quo, most of the 3,800 m^3 of waste is being disposed of at low cost to the generator (by resource recovery, and in one case by neutralization with a waste stream from a nearby firm), and hence even in the absence of restrictions on ocean dumping, this solution would have very limited appeal to firms in Oregon.

The only other high-volume wastes are solid (spent potliners) and have good resource recovery potential. The high cost of ocean disposal for solid materials would render this option uneconomic for these wastes.

Possibilities for deep well injection--Since deep wells are comparatively capital intensive, they are only suitable for high-volume liquid wastes. For the United States, the average volume of industrial waste injected per well is in excess of 200,000 m^3 per year (Reeder et al., 1977). Wells that take less than 10,000 m^3 per year are uncommon (Donaldson, 1972). However, the entire volume of hazardous waste generated in Oregon is only 17,500 m^3 per year (Table 14), and most of it is solid or sludges. The largest single liquid waste stream that is a potential candidate for deep well injection is only about 500 m^3 per year.

In the Willamette Valley there are permeable beds containing saline water which are separated by generally low-permeability marine deposits from the alluvial aquifers that are used extensively for potable water throughout the valley. Any waste injection well in the Willamette Valley would need to be a minimum of 600 m deep, depending on location. (Personal interview, W. Bartholomew, Oregon Water Resources Department, Salem, Oregon, October 7, 1977.) Naturally, the costs would depend on the location and waste type (which affect pretreatment and construction materials). However, the 1977 capital cost of an 800 m deep, low-injection-volume well would probably be at least \$170,000. Thus if amortized at 10 percent per year, the capital charge would be at least \$17,000 per year. In addition, operating costs would be about \$2,000 per year, for a total of at least \$19,000 per year. This figure would barely change if the waste quantity were increased from 500 m^3 per year to 5,000 m^3 per year. (Based on data from L. Reeder, Louis R. Reeder and Associates, Tulsa, Oklahoma, August 24, 1979.)

Five hundred m^3 of waste could be trucked from the Willamette Valley and disposed of at Arlington for about \$20,000 per year. (The typical gate fee at Arlington is \$22 to \$27 per tonne, depending on the waste. [Personal interview, P. Wicks, Chem Nuclear Systems, Inc., Portland, Oregon, March 9, 1977.] The charge for transporting a hazardous waste to Arlington in a fully loaded truck costs about \$16 per tonne from Portland, more from Willamette Valley. [Personal interview, B. Larsen, Widing Transportation, Inc., Portland, Oregon, April 28, 1977.] The cost estimate is based on a specific gravity of 1.0 for an injectable waste.) Disposal at Arlington is one of the lowest risk and highest cost disposal alternatives. Less costly disposal methods might be feasible for many of the wastes, but in any event deep well injection appears unattractive, since its cost is similar to that of disposal at Arlington.

The potential for deep well injection of waste streams from new firms or processes is less clear. Faced with a high-volume waste, there might be the alternative of treating the waste and discharging it to a sewer or surface waters, or using deep well injection. An example of this type was analyzed in Section 6, and for the hypothetical data used, there was a clear generator's cost advantage to deep well injection. There are presently no deep waste disposal wells in Oregon. The practice is against State policy and it would be opposed by the Oregon Water Resources Department, although it has not been totally outlawed. (Personal interview, W. Bartholomew, Oregon Water Resources Department, Salem, Oregon, October 7, 1977.) It does not appear that any firm has seriously pursued the possibility, although at least one has considered it. Hence deep well injection from new processes would need to be analyzed on a case-by-case basis.

Possibilities for land disposal--Land disposal is already extensively used in the status-quo approach, and the main possibility under a market-forces approach would be the use of less costly land disposal. The principal option would be to use local sanitary landfills instead of the Arlington disposal facility.

Since under the market-forces approach, disposal costs may be decreased with respect to the status-quo approach, the question of increased waste generation arises. Data on the price elasticity of demand for waste disposal services are, not surprisingly, rare, and it would require an analysis of each significant individual firm's operations to make any useful predictions. However, it can be expected that even in the long-run, demand would be comparatively inelastic. Data on reduction of BOD in response to sewer charges suggest a price elasticity of less than unity (Elliott and Seagraves, 1972; also see Elliott, 1973; Seagraves, 1973) and it is comparatively easy to reduce BOD loadings in effluents. By contrast, changes in the magnitude of some waste streams could be very difficult to effect, and as already noted, the cost of waste disposal is frequently a small proportion of product value, which tends to lead to inelastic demand. Since data on increased waste generation are not available, this aspect has been neglected.

Resource recovery--The potential for less costly land disposal than in the status-quo approach could reduce resource recovery. However, the largest waste stream going for resource recovery is spent potliners from an aluminum manufacturer, and it is to the company's advantage to practice cryolite recovery on this material, even if the disposal cost were zero. Another significant waste stream, lead metal and oxide wastes (largely from the battery manufacturing industry), falls into a similar position, as is the case with solvents that are reclaimed and a calcium hydroxide sludge that is used by another industry. Examination of the Battelle data suggested that the only likely significant change would be land disposal of a phenol-contaminated calcium carbonate sludge that was sent out of State for lime recovery. It was found that this change had already occurred, as the sludge was being shipped to Arlington.

Regulation-by-Pathways Approach--

The basis of the regulation-by-pathways approach is to require all hazardous wastes actually needing disposal to be disposed of in an environmentally secure manner broadly consistent with the provisions of the RCRA. The only feasible option available for waste disposal (as opposed to treatment or resource recovery) is secure land disposal (incineration is considered to be a treatment process).

Land disposal--Three variations of the regulation-by-pathways approach will be considered. In Scheme I, all hazardous wastes requiring disposal would go to the Arlington facility. In Scheme II, generators would be allowed to construct secure landfills (and lagoons) for disposal of their own wastes. Scheme III includes a public chemical landfill in the Willamette Valley, as well as private secure landfills. There are no abandoned mines suitable for mine disposal in Oregon, so this possibility was not considered.

The feasibility of the various options is strongly influenced by the Oregon climate. Most of the Willamette Valley receives an average of about 100 cm of precipitation per year, largely during the winter (Sternes, 1967). Although there is a deficit in the summer, potential evapotranspiration is less than this (Oregon State University, 1963). Data on open pan evaporation in Oregon are sparse, but those that are available (National Oceanic and Atmospheric Administration, 1976; Sternes, 1967) suggest that an evaporation lagoon could not reliably be used in the Willamette Valley. Hence if lagoons are lined with an impervious barrier to protect the groundwater, they will not constitute a form of disposal--only short term storage. In contrast, Arlington averages 23 cm of annual precipitation (Sternes, 1967), far less than potential evapotranspiration or open pan evaporation. Since it is not possible to get much closer to the Willamette Valley without leaving Oregon's dry zone, there seems little alternative to disposal of dilute aqueous wastes from the Valley at Arlington.

If pesticide wastes, solvents and oils, and wastes that are subject to resource recovery are excluded, sludges and solid wastes from the Willamette Valley total some 6,000 m^3 per year. Under Scheme III, the latter could be disposed of in a chemical landfill within the Valley. To provide adequate safeguards against water contamination, any such landfill would need to be lined and to have a leachate collection system. Residues from leachate treatment might have to be sent to Arlington.

The waste generators in southwest Oregon would probably have to send their wastes to the Willamette Valley chemical landfill proposed above or to Arlington. Waste generators in eastern Oregon would probably use Arlington, but the cost of this would probably cause the aluminum producer in Wasco County (the only large-volume waste generator in eastern Oregon) either to subject its spent potliners to resource recovery, or (under Schemes II and III) to find a local disposal site that could meet the requirements for water protection. (The existing storage/disposal site is very close to the Columbia River, and would be difficult to upgrade adequately.) This firm already has plans to eliminate its flouride-bearing sludge by a change in scrubber technology.

Under Scheme II, it appears unlikely that any other firm would construct its own secure disposal facility. Not only are there no really large waste streams requiring disposal (the largest is 1,200 m^3 per year), but in addition, all the candidate waste streams originate from wet areas. This would preclude local disposal of liquids and would make construction of secure landfills for solids and sludges a costly project.

Waste stream changes, additional treatment and resource recovery--The increased costs of disposal under the regulation-by-pathways approach would probably cause some process changes (to reduce waste) and increased resource recovery. However, the extent of this is difficult to predict. Some wastes might be capable of treatment to render them nonhazardous. For example, phenols are a significant regional waste. The Battelle data indicate that there are eight producers of potentially hazardous phenolic wastes, and permit data show that seven firms regularly expect to ship phenolic wastes to Arlington. (Only three of these firms are coincident with the Battelle list, suggesting that there may be quite a large number of generators of phenolic wastes.) Though there are few options for handling concentrated phenolic wastes except land disposal, biological treatment is feasible at comparatively low cost when the concentration of phenol is low (Rosfjord, Trattner, and Cheremisinoff, 1976). The Battelle and Arlington permit data do not indicate that there are any regular high-volume, low-concentration phenolic waste streams, but if there are, there might be possibilities for treatment of such wastes in conjunction with hardboard and particle board plants (especially in southwest Oregon, where these industries are concentrated).

Another possibility would be to incinerate certain wastes (e.g., solvents, oily wastes and other combustible materials, and also some wastes that are hazardous because of molecular structure as opposed to the presence of hazardous elements). This category could encompass pesticide wastes presently sent to Arlington, and it could include PCB's (at higher cost) if the incinerator had appropriate characteristics. Table 14 shows that there is only a minor quantity (400 m^3 per year) of solvents and oils that are not already subject to resource recovery, and even the total volume of pesticide wastes (which largely originate in the Willamette Valley) is comparatively small (1,100 m^3 per year) in relation to common incinerator capacities (see Powers, 1976). Few other wastes would be appropriate for incineration. Costs for incineration vary extremely widely, depending on the waste stream quantities and characteristics. For example, Scurlock et al. (1975) quote \$0.25 to \$65 per m^3 for liquid injection incineration and \$22 to \$44 per tonne for fluidized bed incineration of sludges. Although not specifically stated, these data tend to assume that the waste stream has a significant calorific value. Hence the dilute aqueous pesticide wastes would be at the top end of the cost range. The upper end of this range is comparable to the cost of transporting a waste from the Willamette Valley and disposing of it at Arlington (approximately \$48 per tonne, or \$48 to \$76 per m^3).

Thus largely because of the small volume of appropriate waste, incineration would not appear to be an economically attractive proposition in Oregon. This tentative finding is confirmed by a report that Chem Nuclear Systems, Inc., performed a more detailed investigation and concluded that installation of an appropriate incinerator would not be profitable in the Pacific Northwest at that time. (Telephone interview, F. Bromfeld, Oregon DEQ, Portland, Oregon, April 17, 1979.)

Development of Threat Scenarios

To proceed with the application of the analytical framework, threat scenarios are needed for all treatment, transport, and disposal techniques that might vary from one approach to another. Although there may be some variation in the threats associated with onsite waste treatment (as opposed to disposal), lack of data precludes analysis of this possibility. However, disregarding treatment threats, it is still appropriate to develop scenarios for threats under the status-quo approach since some of these threats may be eliminated or reduced with alternative approaches to hazardous waste management.

Table 15 identifies some of the most important threats associated with the various techniques that may be used under the three approaches to hazardous waste management being considered. (Refer to Figure 9 for the approach-technique relationships.) The threats specifically associated with deep well injection, ocean dumping and incineration (Threats H, I, and L) are not of immediate interest because the techniques with which they are associated are unlikely to be used under any approach. Table 16 provides more details of the relevant threats. These are still, however, only threat descriptions; quantitative data for a given threat generally depends on the approach, since quantities of wastes, disposal locations, etc., will vary with the approach. Within the constraints of this research, it was not feasible to develop fully all the possible threat scenarios. However, at the end of this section, some have been developed in sufficient detail to illustrate possible methodologies, and limited details on others are included.

It is worth examining the status-quo to see if any threats appear to have materialized. No reliable data could be obtained on industrial accidents involving hazardous wastes in Oregon, and no serious adverse effects on water quality from land disposal have been detected. There have, however, been a number of fish kills arising from various causes. The Oregon Department of Fish and Wildlife is aware of seven pollution-caused incidents in 1975, and 19 in 1976. Total numbers of fish killed are unknown, but they were in excess of 12,000 in 1975 and were probably of the order of 54,000 in 1976. (Data supplied by G. MacLeod, Oregon Department of Fish and Wildlife, Portland, Oregon, October 5, 1977.) Most of these kills were caused accidentally and probably did not involve hazardous wastes (as opposed to hazardous materials). There was one apparent case of illicit hazardous waste dumping. These data suggest that few threats involving hazardous wastes actually materialize under the status-quo approach.

Now that the wastes have been allocated to disposal techniques and the threat scenarios have been developed, the key implications of each approach are summarized in Table 17 to assist the reader in following the subsequent discussion.

Determination of Economic and Social Effects

The most significant economic and social effects are the control costs, and the effects of the threats arising from different disposal methods.

TABLE 15. THREATS ASSOCIATED WITH THREE APPROACHES TO HAZARDOUS WASTE MANAGEMENT

Approach and technique	Threat	Comments
All approaches	A. Transport accidents B. Illicit dumping	
Status-quo		
Local landfilling and lagooning (not secure)	C. Leaching D. Overflow E. Odor	
Secure land disposal (at Arlington)	F. Washout	
Resource recovery	G. Not identified	Changes in resource recovery would probably change in-plant accidents
Market-forces		
Threats A through G plus:		
Deep well injection	H. Water resource contamination	Technique unlikely to be used
Ocean dumping	I. Reduction of ocean-related recreation and industries	Technique unlikely to be used
Regulation-by-pathways		
Threats A,B,D,E,F,G plus:		
Secure local landfilling and lagooning	J. Liner failure	
Waste stream changes	K. Not identified	Would probably affect in-plant accidents
Incineration	L. Air pollution	Technique unlikely to be used

TABLE 16. DESCRIPTIONS OF PRINCIPAL THREATS

	Threat description	Applicability	Comments
A.	Transport accidents Mechanism: Accidents to truck involving loss of cargo. Outcomes: Cleanup requirements, possible damage to life and health.	All approaches	Virtually all Oregon hazardous waste is transported by truck. Very little is flammable/explosive. Event probability is proportional to distance (see Table B-1).
B.	Illicit dumping Mechanism: Dumping on land or to surface waters. Outcomes: Destruction of vegetation, poisoning of livestock, and possibly man (via crops?). Aesthetic damages.	All approaches	The incentive for illicit dumping is least under the market-forces approach, and greatest under the more costly regulation-by-pathways approach. However, opportunities should be diminished under regulation-by-pathways.
C.	Leaching from local landfills and lagoons Mechanism: Leaching from unlined landfills and lagoons. Outcomes: Surface and groundwater contamination leading to fish kills, unsafe drinking water, and aesthetic damages.	Status-quo approach Market-forces approach	This threat is difficult to quantify because the large numbers of sites involved, each with different wastes and hydrologic conditions.
D.	Overflow from lagoons Mechanism: Exceptional precipitation or flood causes lagoon to overflow. Outcomes: Damage to adjacent crops, structures, etc. Cleanup costs.	All approaches (but few lagoons under regulation-by-pathways, since only E. Oregon is suitable)	This threat is difficult to quantify because of the variety of climatic and hydrologic conditions, as well as the variety of wastes that might be involved

(Continued)

TABLE 16 (Continued)

	Threat description	Applicability	Comments
E.	Odor from lagoons and landfills Mechanism: Perceptible odor from lagoon or open landfill operation. Outcomes: Aesthetic degradation, possible reduction in property values.	All approaches	Problem largely arises with organic wastes (e.g., pesticides).
F.	Washout of Arlington secure land disposal site Mechanism: Exceptional precipitation causes washout or excessive leaching of trench and lagoon contents at Arlington waste disposal site. Outcomes: Contamination of some local rangeland and possibly a few wells.	All approaches	Location of site makes washout very unlikely. Leaching problems are even less probable.
J.	Liner failure at secure local landfill Mechanism: Liner at local landfill in wet region of state fails, and leachate is not contained. Outcomes: Local waste contamination leading to fish kills and unsafe drinking water.	Regulation-by-pathways approach (Scheme III only)	Extent of threat is less than that of C, as failure should be detected by monitoring wells before much damage is done.

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TABLE 17. SUMMARY OF APPROACHES

Approach	Waste dispositions	Principal threats
Status-quo	Land disposal	Leaching from local landfills and overflow from lagoons leading to fish kills, etc.
Market-forces	Greater use of local landfills than under status-quo	As above, but more severe
Regulation-by-pathways:		
Scheme I	All wastes to Arlington secure disposal site	Washout of disposal site (unlikely)
Scheme II	Wastes to Arlington, or generator's secure landfill	As above
Scheme III	Same as Scheme II, but western Oregon solids and sludges sent to chemical landfill in the Willamette Valley	Same as above, plus Willamette Valley chemical landfill liner failure, leading to limited fish kills, etc.

Since (with the minor exception of transport accidents) expected values of damages from threats will not be used, the threats will be considered later with regard to their impacts on the parties-at-interest. Control costs are discussed below.

Generators' Costs--

It is not possible to determine accurately the costs of hazardous waste disposal under the status-quo approach, as onsite disposal costs are unknown. In many cases, these are likely to be minimal, and a cost of \$1 per m^3 has arbitrarily been assumed for all onsite disposal. Another problem arises with the transport cost and value of materials being sent for resource recovery. However, since this is not expected to change significantly, these costs have not been evaluated. If the cost of local landfill disposal is \$13 per m^3 and the cost of disposal at Arlington is \$53 per m^3, then the annual generators' cost for the status-quo approach would be \$270,200. Details of the calculations are provided in Table 18, which compares the five schemes and approaches.

Under the market-forces approach, the annual cost would drop to \$98,200. This assumes that only pesticide wastes continue to be sent to Arlington for

TABLE 18. GENERATOR'S COSTS FOR ALTERNATIVE APPROACHES[a]

	Disposition			
Approach	Onsite disposal	Local landfill	Secure disposal at Arlington	Total
Market-forces				
Quantity m^3	5,300	4,700	600	10,600
Annual cost $	5,300[b]	61,100[c]	31,800[d]	98,200
Status-quo				
Quantity m^3	5,300	400	4,900	10,600
Annual cost $	5,300[b]	5,200[c]	259,700[d]	270,200
Regulation-by-pathways	Secure landfill in the Willamette Valley	Local secure landfill (spent potliners)	Secure disposal at Arlington	Total
Scheme I				
Quantity m^3	0	0	10,600	10,600
Annual cost $	0	0	536,500[e]	536,500
Scheme II				
Quantity m^3	0	2,300	8,300	10,600
Annual cost $	0	34,500[f]	439,900[d]	474,400
Scheme III				
Quantity m^3	6,000	2,300	2,300	10,600
Annual cost $	150,000[g]	34,500[f]	121,900[d]	306,400

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[a] Quantities from Table 14, data exclude wastes shipped for resource recovery.

[b] Assuming $1 per m^3. Insufficient data were available for an accurate estimate.

[c] Based on $5 per m^3 gate fee, plus $8 per m^3 for transport an average of 60 km, assuming a specific gravity of 1.2. Sources: Derived from 1975 average U.S. sanitary landfilling cost of $3.59 per tonne (Booz-Allen and Hamilton, 1976). Transport tariff data supplied by B. Larsen, Widing Transportation, Inc., Portland, Oregon, April 28, 1977.

[d] Based on $30 per m^3 gate fee plus $23 per m^3 for transport an average of 300 km, assuming a specific gravity of 1.2. Sources: Disposal fee from personal interview, P. Wicks, Chem Nuclear Systems, Inc., Portland, Oregon, March 9, 1977. Transport tariff data as in c.

[e] Based on 8,300 m^3 at $53 per m^3 (as in d), plus 2,300 m^2 of spent potliner waste at $30 per m^3 gate fee plus $12 for transport 80 km, assuming a specific gravity of 1.5. Sources: As in d.

[f] $15 per m^3 used for illustration. Insufficient data were available to estimate this cost.

[g] Based on $13 per m^3 disposal fee and $12 per m^3 for transport an average distance of 120 km, assuming a specific gravity of 1.2. Sources: Transport tariff data as in c. Disposal cost based on the cost of two hectare landfill of this type constructed in Cowlitz County, Washington, for use with shredded municipal refuse. Conditions at this site should be similar to those in the Portland area. The 1976 capital cost was $6.86 per m^3 of capacity (Telephone interview, M. Kennedy, CH_2M Hill, Portland, Oregon, October 19, 1977). The average 1975 landfill operating cost of $3.15 per m^3 (Booz-Allen and Hamilton, 1976) has been substantially increased to cover additional costs of handling hazardous wastes and leachate treatment.

disposal and that all other chemically landfilled wastes are sent to local landfills.

If, under Scheme I of the regulation-by-pathways approach, all wastes that are not resource-recovered go to Arlington, then the annual generators' cost would rise to $536,500. This figure is based on 8,300 m^3 of wastes at $53, and 2,300 m^3 of spent potliner waste at $42 per m^3. However, this cost for spent potliner disposal would almost undoubtedly prompt the company concerned to negotiate a special contract for disposal at Arlington, or, under Scheme II or III, to either find a local site that could satisfy the various safeguards, or recycle the material. If secure local disposal could be accomplished for $15 per m^3, then the generators' cost would be reduced to $474,400 for Scheme II of the regulation-by-pathways approach.

Recycling of the spent potliner waste might occur under any of the regulation-by-pathways schemes. In the past, part of this waste was recycled at another aluminum producer's facility in Washington. However, this producer is no longer able to take the waste for recycling, and under status-quo conditions, the company has not found it economic to construct its own recycling facility. The possibility of building a regional potliner recycling and cryolite recovery plant to service several aluminum companies has been discussed, but the anti-trust regulations are considered to be a possible barrier to this action.

Under Scheme III of the regulation-by-pathways approach, there is the option of disposing of 6,000 m^3 per year of sludges and solid wastes from the Willamette Valley in a landfill with a liner and leachate collection system located somewhere in the Valley. If disposal cost is $25 per m^3, including leachate treatment, then the generators' costs would be reduced by a further $168,000 to $306,400 per year.

Administrative Costs--

Under the status-quo approach, the Oregon DEQ employed two professionals specifically to deal with hazardous waste issues. Allowing for support services and overheads, this cost can be taken as $100,000 per year. Under the market-forces approach, it might be claimed that no administrative costs would be involved, but the DEQ would probably retain one professional as an adviser ($50,000 per year). Since the regulation-by-pathways approach is broadly equivalent to operation under RCRA conditions, the same projected staffing, i.e., the equivalent of seven full-time professionals at a cost of approximately $300,000 per year can be assumed. (Telephone interview, F. Bromfeld, Oregon DEQ, Portland, Oregon, June 12, 1979.)

These are only the more obvious administrative costs; many other persons (such as Department of Fish and Wildlife employees) might have minor involvement with hazardous wastes, but this cost cannot realistically be evaluated and is probably subject to very little variation between the different approaches.

Social Control Costs--

No social control costs have been identified. Although the fees at certain landfills may not reflect full cost, the use of an average rate avoids this issue. There is also the possibility that the Chem Nuclear fees could reflect monopoly power. However, these fees are somewhat constrained by competition with other treatment, resource recovery, and disposal alternatives (such as the Wes Con disposal facility in Idaho). In view of the extensive front-end costs associated with establishment of the Arlington site, the present fees do not appear to be unreasonably high. Indeed, one of the Oregon DEQ's concerns has been that if the volume of wastes shipped to Arlington fell off too much after the initial backlog of stored wastes had been accepted, Chem Nuclear might not find it economic to continue to operate the disposal site. (Personal interview, F. Bromfeld, Oregon DEQ, Portland, Oregon, March 9, 1977.) This would be a real possibility under the market-forces approach, and ideally the costs of secure disposal should be adjusted to reflect economies of scale.

Other Effects--

Under the three approaches considered, no significant change in resource recovery is anticipated unless cryolite is recovered from the spent potliners. (Such recovery would be particularly desirable, as the United States currently imports 82 percent of its fluorine needs [U.S. Department of the Interior, Bureau of Mines, 1979].) Because of varying truck haulage distances, there are very minor differences in energy consumption among the approaches. All approaches will require about the same area of land for disposal, but the opportunity cost of using this land is higher for the approaches that stress disposal in the fertile and partly urbanized Willamette Valley, as opposed to use of rangeland at Arlington or other arid locations.

Determination of Impacts and Responses of Parties-at-Interest

Although the impacts on the parties-at-interest and their responses are conceptually separate, in practice they may often conveniently be considered together. Determination of the impact involves analyzing how the party-at-interest would be affected by a waste management technique or approach, whereas the party-at-interest's response relates to any action taken as a result of the impact. However, at the broad level of analysis employed here, these two steps have been merged into one that emphasizes the likely attitudes of each party-at-interest. This approach is useful in a planning or policy study, since it provides an indication of where opposition or support for specific plans is likely to be encountered.

Since all approaches emphasize land disposal, and several possible techniques (ocean dumping, deep well injection, and incineration) are unlikely to be used, it is appropriate in this case to consider the reactions of the parties-at-interest to different approaches (philosophies or strategies) as opposed to different techniques (specific technical waste management methods). In Table 19, the author's judgment of the impacts of each approach on the major parties-at-interest has been shown using a seven point (-3 through +3) scale. A weighting factor (1 through 5) for the significance of the parties-at-interest is also included, so that it is possible to compare scores for each approach. Since approaches (not techniques) are being compared, it was considered inappropriate to include the environmental management agency (i.e., the Oregon DEQ). In many respects the

TABLE 19. IMPACTS OF DIFFERENT HAZARDOUS WASTE MANAGEMENT APPROACHES ON THE PARTIES-AT-INTEREST

		Waste management approach				
Weighting Factor	Party-at-interest	Market-forces	Status-quo	Pathways-Scheme I (all wastes to Arlington)	Pathways-Scheme II (all wastes to dry zone disposal sites)	Pathways-Scheme III (including Willamette Valley chemical landfill)
3	Major generators of hazardous wastes	2	1	-3	-1	-1
2	Minor generators of hazardous wastes	2	0	-3	-3	-1
1	Competing firms (different process)	-1	0	1	1	1
1	Waste transport sector	-1	0	2	1	1
1	Firms generating wastes deemed to be nonhazardous	1	0	2	2	2
2	Operators of sanitary landfills	2	0	-1	-1	-1
3	Residents/land owners adjacent to sanitary landfills	-2	-1	0	0	0
2	Operator(s) of secure disposal facilities	-3	1	3	2	2
2	Residents/land owners adjacent to Willamette Valley chemical landfill	*	*	*	*	-2
1	Resource recovery interests	-2	-1	2	1	0
2	Water supply officials	-3	-1	3	2	0
2	Anglers	-2	-1	2	2	1
2	Environmentalists	-3	-2	3	2	1
5	General public	-1	0	1	1	1
	Composite score	-22	-7	17	15	6

* Not applicable

impact on the agency would be some composite of the impacts on the other parties-at-interest, since the agency must respond to all the parties-at-interest.

Waste generators would favor the market-forces approach as it provides them with the greatest flexibility and minimizes their costs. Conversely, they will dislike the three regulation-by-pathways approaches because of the higher costs involved. Firms generating large quantities of wastes (in this case, an aluminum producer was the only firm specifically identified) will find a pathways approach that permits them to establish their own chemical landfills (Scheme II) more attractive than one that does not (Scheme I), whereas smaller generators will be unaffected by this variation. The effect on competing firms is weak, but an interesting situation arises with firms whose wastes are deemed not to be hazardous under the pathways approaches. Instead of being in an ill-defined situation under the status-quo approach, they will be relieved by an official decision on the status of their wastes.

While sanitary landfill operators would in many cases prefer to receive more wastes under the market-forces approach, local residents may feel threatened by these industrial wastes. Conversely, under the pathways approaches, the landfill operators will receive less waste, but the residents will feel more comfortable. The reaction of the chemical landfill operator(s) will depend on the quantities of wastes anticipated.

Despite the prediction that in general there will be little change in resource recovery among approaches, the resource recovery industry will favor the more strict approaches, since the potential for resource recovery will be increased. Water supply officials, environmentalists, and anglers will distrust the market-forces approach because of its threats to water quality and will prefer the pathways approaches, which reduce these threats.

The general public has been included as a party-at-interest. The impact on the public is only weak, but concerned and informed citizens can be expected to prefer the more environmentally secure approaches, especially as the resulting higher costs to generators appear unlikely to have a significant negative impact on local economies.

Although potentially useful, the development of a composite score, as illustrated in Table 19, is highly subjective, especially when it comes to assigning weights to the parties-at-interest. This will be discussed later.

Several possible parties-at-interest have been omitted from Table 19, either on the grounds that impacts on them hardly change between approaches, or that they are too weak to justify inclusion. For example, residents/land owners adjacent to the Arlington disposal site have not been included because the nearest dwelling is 2 km from the disposal area and because any changes in the quantities of wastes received will have little impact on the owners of the rangeland adjoining the site.

Prediction of Outcomes

Waste Dispositions--

In this case study, the prediction of waste dispositions is very simple, and was largely determined when wastes were allocated to techniques.

Under the market-forces approach, most nonpesticide wastes would be landfilled onsite or sent to local landfills, although a few generators would probably still prefer to send wastes to the Arlington disposal site for reasons of environmental consciousness. (Additional costs arising from this possibility have not been included in the evaluation of the market-forces approach.) The latter might include generators of only small quantities of wastes to whom the extra cost was not significant, and major firms that had a high public profile. Firms that were particularly anxious to dispose of responsibility for a waste might be more inclined to use public landfills (possibly through waste hauler services) rather than onsite disposal. However, the concept that a waste generator can rid itself of responsibility for a waste by simply paying another organization to take it away is now being challenged (Taubman, 1979). Use of disposal techniques such as ocean dumping and deep well injection appear unlikely, though the latter might be attractive to some new plants. There might be some reduction in resource recovery where high shipping costs (e.g., to Seattle, Washington) are involved.

Under the regulation-by-pathways schemes, all wastes deemed to be hazardous would be required to be disposed of in chemical landfills or the Arlington facility. This approach would undoubtedly prompt the aluminum producer that is not practicing resource recovery on spent potliners to reexamine the economics of this, and it could encourage other firms to modify their waste streams and increase resource recovery. The extent of increased recovery cannot be predicted. If a chemical landfill for solid wastes and sludges was established in the Willamette Valley, it would divert most of these wastes from Arlington, other than those generated in eastern Oregon. The only significant solid/sludge waste in eastern Oregon is the spent potliners discussed above. If this waste was not subjected to resource recovery, the firm would probably examine the feasibility of establishing a local landfill that complied with the chemical landfill regulations under Scheme II.

Because of higher disposal costs, an increased level of illicit dumping would be expected under the regulation-by-pathways schemes than under the status-quo approach. However, the registration of generators and the use of a manifest system should reduce the opportunities for illicit dumping. Under the market-forces approach, dumping might decrease from the existing low level.

Opposition to Approaches--

Since there appear to be few hazardous waste-related problems under the status-quo approach (such as threats materializing), it seems unlikely that a change in approach would produce very strong reactions, except from any organization very adversely affected. A change to the market-forces approach could be put into effect by an administrative decision to allow local landfills (primarily in the Willamette Valley) to accept more industrial wastes, and this change of policy could be implemented in stages providing an opportunity to gauge public and interest group reactions.

Those most likely to be concerned about the adverse effects that could arise from the market-forces approach would be the water supply officials, anglers, and environmentalists; but residents adjacent to landfills and even the general public could become concerned if the change in approach received "scare" publicity. Though the water supply officials would probably indicate their concern by administrative actions, the other parties-at-interest might mount organized public protests. Although adversely affected, it is unlikely that waste haulers and the resource recovery industry would voice opposition to the market-forces approach, but the impact on the Arlington waste disposal operation would be so strong that the operator would doubtless lobby against the approach. While waste generators would prefer the market-forces approach, they are more likely to address the disposal of specific wastes of interest on a case-by-case basis than to come out strongly in favor of the approach per se.

By contrast, the main opposition to the regulation-by-pathways approach would come from the generators of hazardous wastes, who would object to the increased costs involved. The weight of these objections would be reduced as requirements were made less costly (e.g., Scheme III as opposed to Scheme I). While virtually all the other parties-at-interest will favor the pathways schemes over the status-quo approach, only environmentalists are likely to voice their views publicly. There would probably be opposition to a Willamette Valley chemical landfill (Scheme III) from local residents/property owners, and less support from many of the parties-at-interest for this scheme than for Schemes I or II.

Enumeration of Costs and Impacts

The final step in applying the analytical framework is to collect and summarize the data already generated. In some cases, it would be appropriate to prepare a synopsis for each approach and then to compare approaches--the first step of the decisionmaking phase of the methodology. In this case study, however, these two steps have been combined to produce Table 20.

As soon as the comparison is attempted, a difficulty arises with the threat scenarios. Unlike the case presented in Section 6, where each technique has its own scenario, most of the threat scenarios apply to all five schemes or approaches. Clearly, the intensity of the threat (in terms of the magnitude of the effect or the probability of occurrence) varies between approaches. But except for transport accidents, the descriptions and quantification of the threats presented at the end of this section are not sufficiently detailed to be able to differentiate between approaches. Fortunately, it is comparatively easy to rank the intensity of a given threat as a function of the approach, and this ranking has been included in Table 20. This ranking is possible because threat intensity generally increases with quantities of waste. Ranking the different threats as they apply to a given approach might also be a useful adjunct to decisionmaking, but it has not been attempted, as (in the absence of detailed data and the use of

TABLE 20. COMPARISON OF FIVE HAZARDOUS WASTE MANAGEMENT APPROACHES

	Approach				
	Market-forces	Status-Quo	Regulation by pathways		
			Scheme III	Scheme II	Scheme I
Control Costs (dollars per year):					
Generators' costs[a]	$ 98,200	$ 270,200	$ 306,400	$ 474,400	$ 536,500
Administrative costs	50,000	100,000	300,000	300,000	300,000
Total Control Costs	$ 148,200	$ 370,200	$ 606,400	$ 774,400	$ 836,500
Threat Scenarios:[b]					
A. Transport accidents	5	4	3	2	1
B. Illicit dumping	5	4	3	1	1
C. Leaching from local landfills and lagoons	1	2	*	*	*
D. Lagoon overflow	1	2	3	3	3
E. Odor problems	1	2	3	4	4
F. Arlington site washout	5	4	3	2	1
J. Liner failure at Willamette Valley chemical landfill	*	*	1	*	*
Other Effects:					
Transportation distance[a] (thousands of km)	40	120	116	203	214
Ranking in terms of incentive for resource recovery[b]	5	4	3	2	1
Parties-at-interest composite impact score	-22	-7	6	15	17

* Not applicable.

[a] Excluding materials sent for resource recovery (taken as uniform across approaches).

[b] Ranked by significance across approaches; 1 = most significant, 5 = least.

expected values) it would involve subjective valuations because of the differing natures of the threats.

Section 5 suggests that some iteration may be desirable to optimize the results within an approach. For example, under Scheme III of the regulation-by-pathways approach, the possibility of using more than one chemical landfill in the Willamette Valley could be examined; under the market-forces approach different wastes and alternative dump sites might be considered for ocean dumping. However, the data presented in Table 20 and the preceding sections do reflect some informal iteration during data development, and further iterations are not justified for this case study.

Regulation by Industry (SIC)

It would be conceptually possible to devise an approach to waste management in Oregon that would establish separate regulations for each industry (SIC classification) producing hazardous wastes. This could be a similar approach to that used for controlling discharges to water under the Federal Water Pollution Control Act (PL 92-500), in which the technology to be used for effluent treatment is specified for each industrial sector. However, even at the national level, this has proved to be an immensely complex undertaking, and at the State level, it would involve administrative costs that would almost certainly be out of proportion to the benefits gained by the added sophistication of the approach (compared with regulation-by-pathways, for example).

One attraction of a regulation-by-industry (SIC) approach lies in the possibility of specifying a treatment technology or disposal method that is matched to the characteristics of the waste stream, ideally reaching an optimum trade-off between cost and risk (an optimum trade-off could only be determined if a degree of risk aversion was specified). However, the disadvantage of the approach is the number of industrial categories that would need to be considered. As Table 13 shows, 39 4-digit SIC categories were identified by Battelle as including hazardous waste generators. However, Battelle identified only 96 hazardous waste generating firms from a total of 337 listed in the Directory of Oregon Manufacturers (State of Oregon, Department of Economic Development, 1976). In addition to the SIC's listed in Table 13, other SIC's undoubtedly generate hazardous wastes. For example, many engineering firms have electroplating operations that produce heavy metals wastes, and hence a wide variety of other SIC's could be involved.

One method of solving the SIC problem would be to mandate treatment or disposal methods for wastes from specified processes as opposed to SIC's. However, even if this were done, the sheer number of processes to be dealt with would make this a major undertaking if the approach were to encompass all hazardous wastes. Some check would need to be made on virtually every manufacturing firm (the Directory of Oregon Manufacturers lists approximately 4,600 establishments) and a number of utilities, service companies, and government agencies as well. Furthermore, this approach would only deal effectively with wastes that were generated on a regular basis, primarily process wastes. As noted in Section 3, some hazardous wastes arise from accidents, cleanup operations, off-specification products, and discarded laboratory chemicals. None of these fit well into an approach that involves control on the basis of the processes used. Thus without formal analysis, it appears that an attempt to regulate all hazardous wastes on an industry-by-industry basis at the State level would not be feasible (let alone cost-effective) in view of the immense administrative effort that would be involved.

Another variation of this general approach would be to regulate only selected industries. Two regional industries are obvious candidates--the primary aluminum industry, and the timber products industries that produce phenolic wastes. Two waste streams from the aluminum industry (spent potliners and a calcium fluoride sludge) account for 58 percent of the total hazardous waste in Table 12. The phenolic wastes are significant because they are a major category of waste in the Pacific Northwest, but they are uncommon in other parts of the United States, with the result that they have received little attention in waste management research. (All generators of phenolic wastes identified in Table 12 are resin and glue manufacturers, but it is known that other timber products industries, such as plywood manufacturers, also produce phenolic wastes. One hazardous waste practices study [Gruber and Ghassemi, 1975] deals with some of the SIC's included in Table 13, but does not discuss phenolic waste streams to any significant extent.)

If either the primary aluminum industry or the timber products industries were regulated by mandating treatment or disposal technology, the question of equity would arise: Is it fair that there should be special regulations for certain industries, while others are only subject to some more general regulations? In practice, the ability to specially regulate these industries could be exercised under the status-quo approach by officially designating the aluminum industry wastes and phenols as hazardous wastes. This would have the effect of requiring the wastes to be sent to a licensed secure disposal site if they were disposed of in Oregon. There is, however, an important distinction between these two alternatives. With the regulation-by-industry approach, the waste generator might have little or no latitude in deciding what to do with his waste (e.g., if a specific treatment technology was required), whereas under the status-quo approach, the waste generator would only have to use a specified technology if he wished to *dispose* of the waste. Based on the above discussion, no version of the regulation-by-industry approach appears to be attractive for the situation in Oregon, and the approach has therefore been discarded.

DECISIONMAKING

Array Alternatives and Eliminate Approaches Dominated by Others

In this case study, none of the six schemes or approaches is dominated by any other (see Section 5), and hence none can be eliminated in this way. But the regulation-by-industry approach is too cumbersome (or too inequitable if only a few industries are regulated) to be used in Oregon. This reduces the approaches under active consideration to those listed in Table 20.

Comparison of Results of Approaches With Policy Objectives

None of the approaches is clearly in conflict with the Oregon DEQ's policy objectives (see Policy Objectives earlier in this section), since these are largely framed in nonspecific terms. However, the objective of achieving a reasonable balance between environment, energy, natural resources and economic considerations clearly requires a subjective decision, which could vary considerably between individual decisionmakers.

The DEQ objectives consider energy use. Since incineration is not involved under any of the approaches, the main variation in energy use will be in transportation. It is estimated that (disregarding the wastes sent for resource recovery) the market-forces approach would consume 22 m^3 of diesel fuel per year, compared to 116 m^3 under the regulation-by-pathways (Scheme I) approach. (Based on an average fuel consumption of 0.54 liters per kilometer for heavy trucks without return loads [telephone interview, L. Fishback, Widing Transportation, Inc., Portland, Oregon, June 22, 1979].) The difference between these two extreme energy consumptions would, if produced as heating oil, heat approximately 32 typical single family Oregon homes (based on data from J. Fand, Oregon Department of Energy, Salem, Oregon, August 23, 1979). Of course the cost of the fuel has been included in the generators' costs.

Examination of Trade-offs Between Known Costs and Threats

It is important to recognize that any comparisons involving threats must be subjective since different individuals (both decisionmakers and parties-at-interest) are liable to perceive and compare threats in different ways. Therefore, each decisionmaker must draw his own conclusions from the trade-off analysis, and may disagree with the discussion that follows.

In general, the intensities of Threats A, B, and E (transport accidents, illicit dumping, and odor) appear to be minor compared to C or J (landfill leaching and landfill liner failure). The intensity of Threat D (overflow from lagoons) is probably more site-specific than any other, and will depend on the location and construction of the lagoons. But in general this threat appears to be less significant than C (leaching) with which it is usually associated. By using these assumptions to reduce the number of threats considered, a series of comparisons among the various approaches can now be made.

Market-forces versus Status-quo--

Changing from the status-quo to the market-forces approach reduces control costs by $222,000 per year (see Table 20). The major offsetting damage potential is the increased risk of water pollution from landfill leachate (Threat C) and to a lesser extent from lagoon overflow (Threat D). As shown at the end of this section the value of fishing at risk is about $9.8 million per year. To convert this to a single sum, assume that the problem arises after ten years and persists for five years. The present value of the economic loss would be $14.32 million after discounting at 10 percent per year. This may be compared with a known saving of $1.36 million, i.e., the present value of $222,000 discounted at 10 percent for the ten years before the problem developed.

One problem with this comparison is that Threat C, water pollution from leachate, could arise under the status-quo approach. However, it is clearly a far less intense threat as few industrial wastes reach nonsecure landfills. This could be handled by assigning a threat intensity under the status-quo of, say, 10 percent of the value under the market-forces approach, and treating this as reducing the net present value of the damage potential from $14.32 to $12.89 million.

Since more wastes are sent to Arlington under the status-quo than under the market-forces approach, the consequences of Threat F (site washout) could be more severe under the latter approach. However, it is considered that this threat is unimportant by comparison to that of leaching from nonsecure landfills, and can be disregarded. Hence the main elements in the comparison are a threat involving an economic loss of $12.9 million, compared to a saving of at least $1.36 million if the market-forces approach is preferred to the status-quo. A choice between these two approaches will be dependent on a decisionmaker's perception of Threat C, and his desire for risk aversion.

Regulation-by-pathways Scheme I versus Scheme II--

Under Schemes I and II of the regulation-by-pathways approach the threats from leaching and lagoon overflow (Threats C and D) should be eliminated. Although Scheme I provides slightly more control, Scheme II reduces generators' costs by $62,100 per year (see Table 20) and is more equitable since the generators are given some latitude over the disposal of their wastes. Even though it appears that only one generator is likely to exercise the option to develop his own secure disposal site, the existence of this choice should make the approach appear more reasonable to many parties who might be concerned about the monopoly power that a sole disposal site could exercise. The threats from these two schemes appear to be quite minor. Both washout of the Arlington disposal facility (Threat F) and transport accidents involving cargo loss (Threat A) are expected to occur less than once every 100 years, and would probably cause comparatively minor damage. The probability and effects of leaching or washout of a disposal site for spent potliners (under Scheme II) would depend on the site, but assessment of the risk is simplified by the fact that only two hazardous components, cyanide and fluorine, should be present. Hence Scheme II is preferred to Scheme I of the regulation-by-pathways approach.

Regulation-by-Pathways Scheme II versus Status-quo--

Adoption of Scheme II of the regulation-by-pathways approach instead of the status-quo approach would increase control costs by $404,200 per year (see Table 20). Of this, $200,000 is increased administrative costs which include the operation of a manifest system; hence illicit dumping should not increase. Offsetting the increased control costs is the virtual elimination of Threats C and D (leaching and lagoon overflow). However, under the status-quo approach, these threats are already quite minor (and do not appear to have materialized to date). For example, if as in the previous section, only 10 percent of the full impact of Threat C is considered to apply to the status-quo approach, then the present value of this threat only amounts to $1.43 million, based on the same assumptions about timing. In contrast, the present value of the increase in the control costs is $2.48 million, so if a decisionmaker were to accept these dollar values and timing assumptions, he should logically prefer the status-quo approach if these were the only factors that he considered. Risk aversion is not a factor because the reduction in control costs is greater than the damage cost should the threat materialize--and in practice it may not materialize. Of course, a decisionmaker might wish to make a more comprehensive analysis and take other factors into account.

Regulation-by-pathways Scheme III versus Scheme II--

Scheme III of the regulation-by-pathways approach was developed partly because it was evident that Schemes I and II would be substantially more costly than the status-quo approach, and that they might not offer commensurate environmental advantages. The major threat from Scheme III is a liner failure at the secure landfill in the Willamette Valley (Threat J). It is shown (at the end of this chapter) that should this occur, the cost of countermeasures is expected be about $200,000, plus a small threat (taken as $100,000 per year) to local fishing. In addition, illicit dumping might be reduced in comparison to Schemes I or II. (While a manifest system should virtually eliminate illicit dumping of regularly generated waste streams, wastes that do not occur on a regular basis are still liable to be dumped.) Making the same timing assumptions about threat materialization as above, the present value of the reduction in control costs between Scheme II and Scheme III of the regulation-by-pathways approach is $1.03 million whereas the present value of threat materialization would be only $0.22 million. Changes in other threats between these two alternatives should be minor, so again if these data were considered accurate, and no other factors were taken into account, a logical decisionmaker should prefer Scheme III to Scheme II (or Scheme I) of the regulation-by-pathways approach.

Regulation-by-pathways Scheme III versus Status-quo--

Under Scheme III of the regulation-by-pathways approach, annual control costs are $236,200 greater than under the status-quo approach (see Table 20), but of this difference, $200,000 is increased administrative cost. If all threats other than D and J (landfill leaching and secure landfill liner failure) are disregarded as minor, then using the data already developed, adoption of Scheme III of the regulation-by-pathways approach instead of the status-quo approach would raise the present value of ten years' control costs by $1.45 million, against a reduced present value of threat materialization of $1.21 million. Although on the basis of these data alone a logical decisionmaker should prefer the status-quo to Scheme III of the regulation-by-pathways approach, the numbers are sufficiently close to warrant further investigation. This is particularly important because two quite different approaches are being compared, as opposed to divisions of a single approach (e.g., Scheme II vs. Scheme III of regulation-by-pathways). With a comparison of schemes, many of the factors involved may remain constant or similar (e.g., the nature of a threat remains the same but its intensity changes). This implies that these comparisons should be subject to less uncertainty than those associated with two fundamentally different approaches.

In the above comparison of the status-quo and Scheme III of regulation-by-pathways approaches, in addition to the uncertainty surrounding the threat scenarios, several factors were not considered. A major one is that the benefits of spending an additional $200,000 per year of administrative costs (which will support a manifest system and enhanced waste classification work) are only indirectly incorporated into the foregoing analysis. If part of this additional cost were disregarded in the analysis (on the basis that it provided separate benefits), Scheme III of the regulation-by-pathways approach might be preferable to the status-quo approach. Hence a broader analysis that considers additional factors is needed to choose between these two approaches.

Selection of an Approach

Based on the foregoing discussion, the critical decision in this case study appears to lie in choosing between the status-quo approach and Scheme III of the regulation-by-pathways approach. However, others might disagree with this. For example, an environmentalist might argue that damage to wildlife and aesthetic losses arising from water quality degradation would be beyond valuation, and that such threats should be minimized regardless of cost. This would lead him to favor Scheme I of the regulation-by-pathways approach, or some more stringent approach. In contrast, an industrialist might favor the market-forces approach, but the version of this approach used here is unlikely to attract much additional support. One way to take account of these differing viewpoints is to examine the composite impact score from the parties-at-interest analysis in Table 18. As already noted, such an analysis is highly subjective, but subjective elements are unavoidable at this stage in applying the methodology. Table 18 shows that the approaches that result in a greater anticipated level of environmental protection score higher on the parties-at-interest impact analysis, because most parties-at-interest favor such schemes. (Note that the absolute score is not particularly important--it is relative scores that provide insight.) Scheme III of the regulation-by-pathways approach scores 6, compared to -7 for the status-quo approach. (However, Scheme II of the regulation-by-pathways approach scores 15, which might justify its further examination, even though Scheme III appeared to be clearly preferable when relative control costs and threats were compared.) The decisionmaker can gauge the significance of these differences by comparing them to the entire range of scores, i.e., -22 through 17.

Table 21 provides a summary of key aspects of the two approaches being compared. The present values of 30 years' control costs have been included as representing the costs involved over the entire project life (i.e., 30 years has been taken as planning horizon). If the threats did not materialize until the end of that period their present values would be about 15 percent of the values shown in Table 21. If the recommendation that threat values should not be discounted beyond one generation is adopted, these values would also represent the minumum present values that should be assigned to threat materialization. Use of the 30-year data instead of the 10-year data minimizes the weight given to the threat scenarios.

How the decisionmaker weighs the many factors involved in choosing between these alternatives is (in absence of any specific agency policy guidance) up to him, and the decision should be tested to see how sensitive

TABLE 21. COMPARISON OF TWO HAZARDOUS WASTE MANAGEMENT APPROACHES

Item	Approach	
	Status-quo	Regulation-by-pathways Scheme III
Control Costs:		
Generators' annual costs[a]	$ 270,200	$ 306,400
Annual administrative costs	100,000	300,000
Total	$ 370,200	$ 606,400
Present value of total control costs over 10 years discounted at 10% per year[a]	$ 2,274,700	$ 3,726,100
Present value of total control costs over 30 years discounted at 10% per year[a]	$ 3,489,800	$ 5,716,500
Threat Scenarios		
Major threat scenario:	C. Leaching from local landfills and lagoons	J. Liner failure at secure landfill in Willamette Valley
At risk	Partial loss of fishing valued in total at $9.8 million per year Aesthetic damages	Minor loss of fishing valued in total at $9.8 million per year Aesthetic damages
Dollar estimate	10% loss of fishing ($980,000 per year) from years 11 through 15 Present value=$1,432,100	Counterpuming cost of $200,000 in year 11 Fishing loss of $100,000 in years 11 through 15 Present value=$223,200
Additional risks	Contaminant concentrations might locally become high enough to render well water unsafe. If threat occurs, cost of providing alternative water supply would be involved	Contaminant concentrations might locally become high enough to render well water unsafe. Less likely than under status-quo approach

(Continued)

TABLE 21. (Continued)

Item	Approach	
	Status-quo	Regulation-by-pathways Scheme III
Other threat scenarios:		
A. Transport accidents	Very minor threat	Very minor threat
B. Illicit dumping	No significant difference anticipated	No significant difference anticipated
C. Leaching from landfills, etc.	See above	Judged a very minor threat
D. Lagoon overflow	Judged a minor threat compared to threat C	Judged a very minor threat
E. Odor problems	Can be controlled to be a minor threat	Can be controlled to be a minor threat
F. Arlington site washout	Very minor threat	Very minor threat
Other Effects		
Resource recovery	Little difference in incentive[b]	Little difference in incentive[b]
Energy use: diesel fuel consumption in transportation	65 m^3	63 m^3
Composite score for impact on parties-at-interest[c]	-7	6

[a] Excluding wastes shipped for resource recovery.
[b] Incentive is reduced for Willamette Valley solids and sludges and increased for other wastes.
[c] Range for five approaches evaluated -22 to +17.

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it is to the various assumptions, particularly those like the threat scenarios that are somewhat arbitrary or based on inadequate data. However, it is hoped that use of this methodology will assist a decisionmaker to make better decisions. In this particular case, it has demonstrated that the use of a secure landfill in the Willamette Valley should be worth further detailed examination. Under the RCRA only regulation-by-pathways approaches would be permissible, but Scheme III should be feasible and could prove attractive in comparison to Schemes I or II.

APPENDIX: DEVELOPMENT OF CERTAIN THREAT SCENARIOS

Scenario A - Transport Accidents

As far as is known, no hazardous waste is transported in Oregon by rail or barge. Table B-1 quotes a national accident rate of 17 events per billion kilometers for tank trucks involving cargo loss. There is no reason to assume that this rate is not characteristic of carriers in Oregon, and it will be assumed that it also applies to trucks carrying solid wastes (usually in the form of 208-liter [55-gallon] drums).

Though all accidents involve costs (which should be covered by insurance and thus reflected in the haulage rates), only where there is a spill are costs imposed that specifically relate to hazardous wastes. If it is assumed that the average load is 25 m^3, in the worst case situation (in which all the 10,600 m^3 of nonresource-recovered wastes included in Table 14 are assumed to be trucked an average of 300 km) the accident frequency will be 2.2×10^{-3} events per year. Since the variation among approaches would be less than this, and since in many cases the damage would be largely restricted to cleanup costs for toxic materials (only $25,000 per accident even at $1,000 per m^3 of cargo), transport accidents can be largely ignored in the analysis.

Scenario C - Leaching from Local Landfills and Lagoons

The worst leaching would occur under the market-forces approach, as (apart from pesticides) local disposal in unlined landfills is expected to increase. The most potent contaminants to be found in the non-pesticide wastes are probably heavy metals. Other wastes that might go to these landfills contain biodegradable materials (e.g., phenols), materials that are hazardous by virtue of their pH, and solvents and oils that present a fire and explosion threat.

All known firms with wastes that contain heavy metals are in the Willamette Valley. From the Battelle data, it is estimated that the 1,956 m^3 of these wastes shown in Table 12 that are not subject to resource recovery contribute approximately 135 tonnes of heavy metal ions. If allowance is made for increasing effluent standards, this is expected to rise to 150 tonnes, considering only those firms for which effluent data were available. When allowance is made for waste streams for which there were insufficient data, the total quantity of heavy metal ions is expected to be about 205 tonnes. The approximate proportions (percent by weight) of the various metal ions (excluding wastes subjected to resource recovery) is as follows:

Chromium	42.3%
Copper	28.6
Zinc	22.8
Nickel	3.5
Cadmium	1.5
Lead	1.0
Others (includes barium, silver, gold)	0.3
Total	100.0%

This estimate is based on the Battelle data, assuming that the ion content in the wastes for which insufficient data were available is the same as in the known waste streams.

The mean annual discharge of the Willamette River at its mouth at Portland has been estimated to be 1,077 m^3/s, and the corresponding flow at Salem is 752 m^3/s. The mean annual flow of the Columbia River at Portland has been estimated to be about 6,958 m^3/s (Orem, 1968). If 205 tonnes per year of metal ions, composed as shown above, were leached into the Willamette or Columbia Rivers in the vicinity of Portland, the expected average concentrations of metal ions are shown in Table 22. This table also includes the quality standards for the river waters and for potable water supply.

TABLE 22. THEORETICAL AVERAGE CONCENTRATIONS OF IONS FROM HEAVY METALS WASTES AT PORTLAND, AND RELEVANT STANDARDS (ppb)

Ion	Drinking water quality standard[a]	Oregon water quality standard[b]	Calculated concentrations from heavy metals wastes[c] Willamette River	 Columbia River
Chromium	50	50	2.55	0.39
Copper	1,000	5	1.73	0.27
Zinc	5,000	100	1.38	0.22
Nickel	d	d	0.21	0.03
Cadmium	10	10	0.09	0.01
Lead	50	50	0.06	0.01
Others	-	-	0.02	e
Total	-	500	6.04	0.93

[a] Standard for domestic water supplies (Source: U.S. Environmental Protection Agency, 1976d).

[b] Standards for Multnomah Channel (Columbia River) and Main Stem Willamette River (OAR 41-045).

[c] Based on 205 tonnes of heavy metal ions distributed as given in the text. River flow data are also given in the text.

[d] Not quoted.

[e] <0.01 ppb.

Even for the Willamette River, the concentrations are at least an order of magnitude below the quality standards established for potable water, so this risk has not been analyzed. The possibility of higher concentrations affecting water supplies should be borne in mind when considering this threat.

The effects that the metals might have on fish and other aquatic life vary widely with circumstances and species.* Salmonids--the fish of preeminent concern in Oregon--are among the most sensitive, although bioaccumulation is not a problem as it is with shellfish. The concentration at which the presence of metal ions affects fish depends on the water's hardness and alkalinity. The effects depend on the type of ion (e.g., hexavalent versus trivalent chromium) and on the conjunctive presence of ions. For example, cadmium and copper, and zinc and copper have more severe effects in conjunction than individually. The effects of concern are not restricted to the levels for acute or chronic mortality. Fish may sense lower concentrations and avoid the area. This may preclude anadromous fish (such as many species of salmonids) from returning to their spawning grounds--thereby decimating the fishery.

For chromium, fish mortality effects may occur at 20 ppb, but they do not usually become apparent until higher concentrations. Some research with very high concentrations (5,000 ppb) has not resulted in mortality. Hexavalent chromium is generally more toxic than the trivalent form, and invertebrates are frequently more sensitive than vertebrates. With copper, sublethal effects are observed at 5 ppb, and fish mortality may occur at 10 to 20 ppb. Mortality for zinc is not observed below 100 ppb; and for nickel, chronic effects (via eggs) occur at 700 ppb. Cadmium can be lethal to fish at as low as 1 ppb, but this rises to 9 ppb in hard water. Fish mortality occurs at 300 to 600 ppb for lead.

If these lethal concentrations are compared with those given in Table 22 for the Willamette River, it will be seen that the metals that are most likely to cause problems are chromium and copper. Although they are close with respect to copper, the concentrations do not exceed the Oregon water quality standards for that location. (These standards are presumably intended to protect both aquatic and human life.) However, it must be remembered that the concentrations given in Table 22 are additional to preexisting levels.

Evaluating the actual risk is difficult. In practice, most of the metals enter the landfill in a relatively insoluble form (e.g., hydroxide sludges), but they could be released, depending on pH. If they are released, concentrations could be attenuated by ion-exchange with the intervening soils. On the other hand, Elzy et al. (1974) (also see Elzy and Lindstrom,

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* This section is based on personal discussions with H. Lorz, Oregon Department of Fish and Wildlife, and G. Chapman, EPA, at the EPA Western Fish Toxicology Station, Corvallis, Oregon on October 4, 1977. The discussion was specific to the conditions and species of relevance to Oregon. (Also see U.S. Environmental Protection Agency, 1976d; Van Hook, 1978; National Academy of Science, National Academy of Engineering, 1972.)

1976) have modelled the release of leachates from landfills, using a case study, of a landfill on Brown's Island adjacent to the Willamette River near Salem, Oregon. They showed that the release of elements would occur in pulses, which could reach quite high concentrations. The pulses relate to precipitation and water table height at the landfill. Unfortunately it is not feasible to simply extrapolate Elzy et al.'s results to simulate concentrations at Portland, as behavior is nonlinear except at low concentrations. However, the complete computer model could be rerun to provide a more accurate prediction of the concentrations that might occur in Oregon's rivers if various wastes were deposited in specified landfills. (Personal interview, T. Lindstrom, Oregon State University, Corvallis, Oregon, October 3, 1977.) It must also be remembered that flow rates in the rivers vary considerably throughout the year and from year to year.

Without far more extensive analysis, it is difficult to determine whether or not the concentrations of heavy metals that might leach from landfills in the Willamette Valley could affect aquatic life in the Willamette River. It certainly appears possible that concentrations could be high enough to affect parts of the river system. Concentrations in the Columbia should be lower, and the Oregon DEQ's practice of directing marginal wastes to the St. Johns landfill (which must leach into the Columbia River) rather than to other landfills further up the Willamette Valley appears to be wise. The city of Portland has tested the water near to the St. Johns landfill, but apart from chlorides and iron, could not detect any elevated levels of contaminants such as heavy metals. (Personal interview, H. Edwards, L. Brownson and D. Steiner, Office of the City Engineer, Portland, Oregon, April 27, 1977.) It would also be useful to compare the likely increases in heavy metals concentrations in the Willamette and Columbia Rivers with existing levels. This step was not taken, because although there are numerous water quality data for these rivers, these particular parameters are not yet regularly monitored (U.S. Environmental Protection Agency, 1974c; State of Oregon, Department of Environmental Quality, 1976a, 1976b). Most data that do exist on heavy metals in these rivers relate to those in the bottom sediments, as opposed to dissolved heavy metals that would affect fish. (Telephone interview, S. McKenzie, U.S. Geological Survey, Portland, Oregon, August 23, 1979. However, see J. Rinella and S. McKenzie, 1977.)

By determining the value of fishing on the Willamette River system, one could obtain an indication of the cost of the potential threat from waste disposal. In one way, this estimate might overstate the damage, as some anglers would move to other rivers. However, there would also be aesthetic damages and secondary effects such as reductions in the populations of raptors that are dependent on the fish. Given sufficient resources, it might be possible to come up with dollar estimates for most of these effects. But for the present purpose, it is probably satisfactory to concentrate on the direct effect on the fishery.

Good data are available on the numbers of anadromous fish that "run" the Columbia, Willamette, and other Oregon rivers, and estimates for fishing effort are available. In 1977, it was estimated that anglers spent 246,148 angler-days fishing for salmon and steelhead on the Willamette River system. Most of this fishing was by boat on the lower portion of the river in the greater Portland area. (Telephone interview, D. Swartz, Oregon Department of Fish and Wildlife, Portland, Oregon, May 8, 1979. Data largely based on Lowry, 1978.) An angler-day of this type of fishing is valued at $30.80 (Oregon Department of Fish and Wildlife, 1977) for a total annual value of $7.6 million. It can be assumed that all this fishing is at risk, because the salmonids would be deterred from returning to any part of the Willamette to spawn. In addition to salmon and steelhead fishing, another 931,197 angler-days are expended on other types of fish, predominantly trout. Although some of these fish are anadromous, for simplicity it will be assumed that all are resident and that a landfill would only threaten the lower Willamette (below Oregon City). In this event, only 216,280 angler-days worth $2.2 million would be at risk, for a total of $9.8 million. (The $2.2 million is based on $10.60 for resident trout and $8.82 for most other game fish [Oregon Department of Fish and Wildlife, 1977].) In practice, it would be most unlikely that all the fish that live in or pass through the lower Willamette would be killed, so some fishing would continue, making the $9.8 million per year a limiting (high) estimate of the direct effect. However, as already noted, aesthetic and secondary effects have not been included in this evaluation.

If landfills that accepted toxic materials were located higher up the Willamette Valley (e.g., at Eugene/Springfield), more fishing could be at risk depending on the distribution of contaminant concentrations in the river system. Based on the predeeding data, the total annual value of fishing on the entire Willamette River system is $17.2 million, but fishing over the entire system would not be destroyed, since there would be some resident fish on sections unaffected by landfills.

Scenario D - Overflow from Lagoons

Since lagooning for evaporation is feasible only in eastern Oregon, the potential for lagooning is limited. In Table 12, the bulk of the material that is lagooned (3,817 m^3 per year) is a calcium fluoride sludge that the firm already has plans to eliminate. Much of the remainder (492 m^3 per year) is a very dilute pesticide waste (wash water) from a pesticide formulator in the Portland area. This probably poses a leaching threat as well as an overflow threat, because if leaching did not occur, the lagoon would be expected to fill up. But as a result of the very low concentrations involved, the Oregon DEQ has not required the waste to be disposed of at Arlington (telephone interview, E. Chiong, Oregon DEQ, Portland, Oregon, June 5, 1979), and so it can be assumed that the overflow threat is perceived as being relatively minor. Other lagoons involve only small annual quantities of wastes. Hence without further analysis, it is possible to argue that the magnitude of the overflow threat is far less than that of leaching. However, without knowing more details of the lagoons, it is not possible to assess the threat probability.

Scenario E - Odor from Lagoons and Landfills

This problem is not, of course, peculiar to hazardous wastes, but it has been included because it is frequently the trigger for citizen complaints. At the lowest level, the problem is aesthetic and no permanent damage is done, but it could have an adverse effect on the value of properties adjacent to the relevant disposal site. As far as is known, none of Oregon's hazardous wastes give rise to extensive air pollution capable of causing significant physiological damage to living organisms or physical damage to structures.

Scenario F - Washout of Arlington Secure Land Disposal Site

A geologist's report on the Arlington site (Newcomb and Deacon, 1971) evaluates the possibility of water contamination arising from various causes (e.g., leaching, major flood, volcanic activity, landslides, faulting and earthquakes). The actual disposal site includes a natural closed depression (some 18 m deep) used for the lagooning operations, but the disposal trenches are on higher ground. The report shows that the depth to usable groundwater in a confined aquifer of Columbia River basalt group at the Arlington site is 152 m. The report concludes that because of the low rainfall (average of 25 cm per year) and high evaporation demand (average of 160 cm per year), water is generally not transmitted downwards, and what does escape is absorbed locally and does not threaten the basalt aquifer. The report states that the possibility of operations being affected by landslides, faulting, earthquakes, ash falls and lava flows from volcanic activities are each less than one event in 10,000 years. It also states that the site is so well protected that a regional catastrophe (such as the blocking of the Columbia drainage) would be necessary to flood the site, which should occur less than once in 10,000 years.

Though these findings suggest that the threat potential from the Arlington site is very low, the greatest threat would still appear to be some sort of precipitation-induced event, such as washout of the disposal trenches or excessive leaching following a very exceptional storm. There are two wells within 2 km of the site, and these, together with some of the rangeland, could conceivably be affected. If so, the use of this land could be lost for several years, and the wells might have to be extended to a lower aquifer. As a first approximation, the costs involved are estimated to be $100,000, being largely well redevelopment.

Scenario J - Liner Failure at Secure Local Landfill

If a secure landfill was constructed in the Willamette Valley, a liner would be necessary to protect the groundwater. If this liner failed, failure would be detected by monitoring wells and suitable countermeasures taken. These could include covering the landfill surface with an impervious material to prevent water ingress, and the drilling and pumping of interceptor wells. Even so, some of the leachate could escape, but the quantity would be comparatively small. Assuming some ten interceptor wells were drilled to a depth of 30 m, the cost of the countermeasures might be $200,000 (based on data from L. Reeder, Louis R. Reeder and Associates, Tulsa, Oklahoma, August 24, 1979). The value of fishing threatened would be far less than that of Scenario C--perhaps $100,000 per year for five years.

A further risk is that the contamination might travel sufficiently far to affect some wells, in which event an alternative water supply would be required. However, because of the use of monitoring wells, damage to health should be avoided.

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REFERENCES

Abrams, E.F., D.K. Guinan, and D. Derkics. *Assessment of Industrial Hazardous Waste Practices, Textiles Industry*. SW-125c, U.S. Environmental Protection Agency, Washington, D.C., 1976. 276 pp. [NTIS:PB258953]

Anderson, F.R., A.V. Kneese, P.D. Reed, R.B. Stevenson, and S. Taylor. *Environmental Improvement Through Economic Incentives*. The Johns Hopkins University Press, Baltimore, Maryland, 1977. 207 pp.

Anon. "A Nightmare in Niagara." *Time*, 112(7):46, 1978a.

Anon. "Focus: In the Publc Eye." *Electronics and Power*, 24(5):333, 1978b.

Anon. "Love Turned Sour." *The Economist*, 268(7041):30,31, 1978c.

Arbuckle, J.G., M.A. James, M.L. Miller, and T.F.P. Sullivan. *Environmental Law Handbook*. Government Institutes, Inc., Washington, D.C., 1976. 423 pp.

Arrow, K.J., and T. Scitovsky, eds. *Readings in Welfare Economics*. Richard D. Irwin, Inc., Homewood, Illinois, 1969. 740 pp.

Arthur D. Little, Inc. *Alternatives to the Management of Hazardous Wastes at National Disposal Sites*. 2 volumes. EPA/530/SW-46c, U.S. Environmental Protection Agency, Washington, D.C., 1973. [NTIS:PB225164, PB237264]

Arthur D. Little, Inc. *Pharmaceutical Industry; Hazardous Waste Generation, Treatment, and Disposal*. SW-508, U.S. Environmental Protection Agency, 1976. 190 pp.

Ayres, R.U., and A.V. Kneese. "Production, Consumption, and Externalities." *American Economic Review*, 59(3):282-297, 1969.

Backman, J. "Pricing." In: *Science in Marketing*, G. Schwartz, ed. John Wiley and Sons, New York, New York, 1965. pp. 250-280.

Barnett, H.J., and C. Morse. *Scarcity and Growth: The Economics of Natural Resource Availability*. The Johns Hopkins University Press, Baltimore, Maryland, 1963. 304 pp.

Barr Engineering Co. *Hazardous Waste Generation: Twin Cities Metropolitan Area*. Barr Engineering Co., Minneapolis, Minnesota, 1973.

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Barrager, S.M., B.R. Judd, and D.W. North. *The Economic and Social Costs of Coal and Nuclear Electric Generation; A Framework for Assessment and Illustrative Calculations for the Coal and Nuclear Fuel Cycles*. U.S. Government Printing Office, Washington, D.C., 1976. 138pp.

Battelle-Columbus Laboratories. *Assessment of Industrial Hazardous Waste Practices; Electroplating and Metal Finishing Industries*. SW-136c, U.S. Environmental Protection Agency, Washington, D.C., 1976. [NTIS: PB264394]

Battelle Memorial Institute, Pacific Northwest Laboratories. *Program for the Management of Hazardous Wastes*. 2 volumes. EPA-530/SW54c, U.S. Environmental Protection Agency, Washington, D.C., 1974. [NTIS: PB233630/1]

Bell, D.E., R.L. Keeney, and H. Raiffa. *Conflicting Objectives in Decisions*. John Wiley and Sons, New York, New York, 1977. 452 pp.

Berkowitz, J.B., F. March, and R. Horne. *Industrial Solid Waste Classification Systems*. EPA-670/2-75-024, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1975. 412 pp.

Bishop, J., and C. Cicchetti. "Some Institutional and Conceptual Thoughts on the Measurement of Indirect and Intangible Benefits and Costs." In: *Cost Benefit Analysis and Water Pollution Policy*, H.M. Peskin and E.P. Seskin, eds. The Urban Institute, Washington, D.C., 1975. pp. 105-126.

Bohm, P. *Social Efficiency: A Concise Introduction to Welfare Economics*. John Wiley and Sons, New York, New York, 1973. 167 pp.

Booz-Allen and Hamilton, Inc. *Cost Estimating Handbook for Transfer, Shredding and Sanitary Landfilling of Solid Waste*. SW-124c, U.S. Environmental Protection Agency, Washington, D.C., 1976. 83 pp. [NTIS: PB256444]

Booz-Allen Applied Research, Inc. *A Study of Hazardous Waste Materials, Hazardous Effects and Disposal Methods*. Volumes 2 & 3. EPA-670/2-73-15 and 16. U.S. Environmental Protection Agency, Cincinnati, Ohio, 1972. [NTIS:PB221466/7]

Cannon, J.S. *Environmental Steel: Pollution in the Iron and Steel Industry*, J.M. Halloran, ed. Praeger Publishers, New York, New York, 1974. 535 pp.

Chase, S.B., Jr., ed. *Problems in Public Expenditure Analysis*. The Brookings Institution, Washington, D.C., 1968. 283 pp.

Cook, T.D., ed. *Underground Waste Management and Environmental Implications*. Memoir 18, The American Association of Petroleum Geologists, Tulsa, Oklahoma, 1972.

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PAGE NUMBER

Corson, A.S., ed. *Proceedings: 1975 Public Meetings on Hazardous Waste Management*. 2 volumes. SW-9p, U.S. Environmental Protection Agency, 1976. 1750 pp.

Council on Environmental Quality. *Ocean Dumping: A National Policy*. U.S. Government Printing Office, Washington, D.C., 1970. 45 pp.

Council on Environmental Quality. *Environmental Quality: The Eighth Annual Report*. U.S. Government Printing Office, Washington, D.C., 1977. 475 pp.

Crumpler, E.P., Jr. *Management of Metal-Finishing Sludge*. SW-561, U.S. Environmental Protection Agency, Washington, D.C., 1977. 65 pp. [NTIS: PB263946]

Donaldson, E.C. "Injection Wells and Operations Today." In: *Underground Waste Management and Environmental Implications*, T.D. Cook, ed. Memoir 18, The American Association of Petroleum Geologists, Tulsa, Oklahoma, 1972. pp. 24-46.

Edelman, A., D. Huber, A. Kohan, J. Kooyoomjian, C. Metcalf, C. Porter, M. Shannon, and R. Testani. *Hazardous Waste Management: Issue Analysis From Discussions at Four Public Meetings, December 1975*. SW-524, U.S. Environmental Protection Agency, 1976.

Elliott, R.D. "Economic Study of the Effect of Municipal Sewer Surcharges on Industrial Wastes and Water Usage." *Water Resources Research*, 9(5): 1121-1131, 1973.

Elliott, R.D., and J.A. Seagraves. *The Effects of Sewer Surcharges on the Level of Industrial Wastes and the Use of Water by Industry*. Report No. 70, North Carolina Water Resources Research Institute, Raleigh, North Carolina, 1972. 53 pp. [NTIS:PB213267]

Elzy, E., and F.T. Lindstrom. "Model of the Movement of Hazardous Waste Chemicals for Sanitary Landfill Sites." In: *Proceedings of the Conference on Environmental Modeling and Simulation*, W.R. Ott, ed. EPA-600/9-76-016, U.S. Environmental Protection Agency, Washington, D.C., 1976. pp. 609-613.

Elzy, E., F.T. Lindstrom, L. Boersma, R. Sweet, and P. Wicks. "Model of the Movement of Hazardous Waste Chemicals In and From a Landfill Site." In: *Disposal of Environmentally Hazardous Wastes*, Oregon State University Environmental Health Sciences Center Task Force on Environmentally hazardous Wastes, Corvallis, Oregon, 1974. pp. 111-201.

Executive Office of the President, Office of Management and Budget. "Subject: Discount Rates to be Used in Evaluating Time-Distributed Costs and Benefits." Circular No. A-94 (Revised), Office of Management and Budget, Washington, D.C., 1972. 6 pp.

Farb, D., and S.D. Ward. Information About Hazardous Waste Management Facilities. EPA/530/SW-145, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1975. 138 pp.

Fennelly, P.F., M.A. Chillingworth, P.D. Spawn, and M.I. Bornstein. The Generation and Disposal of Hazardous Wastes in Massachusetts. GCA-TR-76-29-G, GCA Corporation, GCA/Technology Division, Bedford, Massachusetts, 1976. 127 pp.

Fischhoff, B. "Cost Benefit Analysis and the Art of Motorcycle Maintenance." Policy Sciences, 8(2):177-202, 1977.

Fishburn, P.C. Decision and Value Theory. John Wiley and Sons, Inc., New York, New York, 1964. 469 pp.

Fisher, A.C., and J.V. Krutilla. "Valuing Long Run Ecological Consequences and Irreversibilities." Journal of Environmental Economics and Management, 1(2):96-108, 1974.

Fisher, A.C., and F.M. Peterson. "The Environment in Economics: A Survey." Journal of Economic Literature, 14(1):1-33, 1976.

Flinn, J.E., T.J. Thomas, and M.D. Bishop. Identification Systems for Selecting Chemicals or Chemical Classes as Candidates for Evaluation. EPA-560/1-74-001, U.S. Environmental Protection Agency, Washington, D.C., 1974. 153 pp. [NTIS:PB238196]

Foster D. Snell, Inc. Assessment of Industrial Hazardous Waste Practices, Rubber and Plastics Industry. 3 volumes. Contract No. 68-01-3194, U.S. Environmental Protection Agency, Washington, D.C., 1976a. [Draft.]

Foster D. Snell, Inc. Potential for Capacity Creation in the Hazardous Waste Management Service Industry. SW-127c, U.S. Environmental Protection Agency, Washingtion, D.C., 1976b.

Freeman, A.M. III, R.H. Haveman, and A.V. Kneese. The Economics of Environmental Policy. John Wiley and Sons, Inc., New York, New York, 1973. 198 pp.

Ghassemi, M., and S. Quinlivan. A Study of Selected Landfills Designed as Pesticide Disposal Sites. EPA/530/SW-114c, U.S. Environmental Protection Agency, Washington, D.C., 1975. 140 pp. [NTIS:PB250717]

Gilmore, J.S., W.M. Beaney, P.I. Bortz, M.K. Duff, and T.D. Nevens. Environmental Policy Analysis; Public Policy Intervention in Inter-Industry Flows of Goods and Services to Reduce Pollution. NSF Grant GI-11, Denver Research Institute, University of Denver, Denver, Colorado, 1971. 150 pp.

Goldstein, B.D. "Assessment of the Health Effects of Stationary Source Fossil Fuel Combustion Products." In: *Risk Benefit Methodology and Application: Some Papers Presented at the Engineering Foundation Workshop, September 22-26, 1975, Asilomar, California*, D. Okrent, ed. UCLA-ENG-7598, School of Engineering and Applied Science, University of California, Los Angeles, California, 1975. pp. 103-116.

Gruber, G.I., and M. Ghassemi. *Assessment of Industrial Hazardous Waste Practices, Organic Chemicals, Pesticides and Explosives Industries.* SW-118c, U.S. Environmental Protection Agency, Washington, D.C., 1975.

Hardin, G. "The Tragedy of the Commons." *Science*, 162(3859):1243-1248, 1968.

Haskell, E.H., and V.S. Price. *State Environmental Management: Case Studies of Nine States*. Praeger Publishers, New York, New York, 1973. 310 pp.

Haveman, R.H., and B.A. Weisbrod. "The Concept of Benefits in Cost-Benefit Analysis: With Emphasis on Water Pollution Control Activities." In: *Cost Benefit Analysis and Water Pollution Policy*, H.M. Peskin and E.P. Seskin, eds. The Urban Institute, Washington, D.C., 1975. pp. 37-66.

Herfindahl, O.C., and A.V. Kneese. *Economic Theory of Natural Resources.* Charles E. Merrill Publishing Company, Columbus, Ohio, 1974. 415 pp.

Jacobs Engineering Co., Inc. *Assessment of Industrial Hazardous Waste Practices, Petroleum Refining*. SW-129c, U.S. Environmental Protection Agency, Washington, D.C., 1976. [NTIS:PB259097]

Kennedy, R., R. Lowrey, A. Bernstein, and F. Rueter. *A Benefit-Cost System for Chemical Pesticides*. EPA 540/9-76/001, U.S. Environmental Protection Agency, Washington, D.C., 1976. 322 pp. [NTIS:PB250988]

Klee, A.J. "Models for Evaluation of Hazardous Wastes." *Journal of the Environmental Engineering Division*, Proceedings of the American Society of Civil Engineers, 102(EE1) 111-125, February 1976.

Klein, F.C. "Friendly Reaction: Nuclear Power Plant, Clean and Quiet, Wins Approval of Neighbors" *Wall St. Journal*, Jan. 16th, 1978, pp. 1,27.

Kohan, A.M. *A Summary of Hazardous Substance Classification Systems*. EPA/530/SW-171, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1975. 59 pp.

Kotler, P. *Marketing Management; Analysis, Planning and Control*. Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1967. 640 pp.

Kovalick, W.W. (Chairman) *Report of the Non-Sewage Sludge/Residuals Work Group*. 2 volumes. U.S. Environmental Protection Agency, Washington, D.C., 1975. [Draft]

TYPING GUIDE SHEET
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Lackey, L.L., T.O. Jacobs, and S.R. Stewart. *Public Attitudes Toward Hazardous Waste Disposal Facilities*. EPA-670/2-73-086, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1973. 195 pp. [NTIS:PB 223638]

Lave, L.B., and E.P. Seskin. "Air Pollution and Human Health." *Science*, 169(3947):723-733, 1970.

Lehman, J.P. "Status of Legislation, Grants and Proposed Hazardous Waste Regulations." *Journal of Environmental Health*, 39(2):83-86, 1976.

Leonard, R.P., R.C. Ziegler, W.R. Brown, J.Y. Yag, and H.G. Reif. *Assessment of Industrial Hazardous Waste Practices in the Metal Smelting and Refining Industry*. 3 volumes. EPA/530/SW-145, U.S. Environmental Protection Agency, 1975. [NTIS:PB276172]

Lipsey, R.G., and K. Lancaster. "The General Theory of Second Best." *The Review of Economic Studies*, 24:11-32, 1956.

Louis Harris and Associates, Inc. *A Second Survey of Public and Leadership Attitudes Toward Nuclear Power Development in the United States*. Ebasco Services Incorporated, New York, New York, November 1976.

Lowry, H. *1977 Oregon Anglers Survey*. Survey Research Center, Oregon State University, Corvallis, Oregon, September 1978.

Maass, A. "Benefit-Cost Analysis: Its Relevance to Public Investment Decisions." *Quarterly Journal of Economics*, 88(2):208-226, 1966.

Maderthaner, R., P. Pahner, G. Guttmann, and H.J. Otway. *Perception of Technological Risks: The Effect of Confrontation*. RM-76-53, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976. 24 pp.

Mäler, K.G., and R.E. Wyzga. *Economic Measurement of Environmental Damage; A Technical Handbook*. Organisation for Economic Cooperation and Development, Paris, France, 1976. 151 pp.

McCandless, L.C., R. Wetzel, J. Casana, and K. Slimak. *Assessment of Industrial Hazardous Waste Practices, Storage and Primary Batteries Industries*. EPA 530/SW-102c, U.S. Environmental Protection Agency, Washington, D.C., 1975. 258 pp. [NTIS:PB241204]

McKean, R.N. "The Use of Shadow Prices." In: *Problems in Public Expenditure Analysis*, S.B. Chase, Jr., ed. The Brookings Institution, Washington, D.C., 1968. pp. 33-77.

Mehlhaff, L.C., T. Cook, and J. Knudson. "A Quantitative Approach to Classification of Hazardous Waste." In: *Proceedings of a National Conference about Hazardous Waste Management*, E.B. Workman, ed. Vector and Waste Management Section, California State Department of Health, Sacramento, California, 1978. pp. 267-272.

BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
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3/8"

PAGE NUMBER

Merrett, A.J., and A. Sykes. *The Finance and Analysis of Capital Projects*. Longmans Green and Co. Ltd., London, England, 1963. 564 pp.

Midwest Research Institute. *A Study of Waste Generation, Treatment and Disposal in the Metals Mining Industry*. Volume 1. SW-132c, U.S. Environmental Protection Agency, Washington, D.C., 1975. [NTIS-PB261052]

Miller, D.W. "Decontaminate Water Before It Gets Into the Ground." *Water and Sewage Works*, 121(6):51-53, 1974.

Milliken, J.G., and G.C. Taylor. *Metropolitan Water Management*. Water Resources Monograph Series #6, American Geophysical Union, Washington, D.C., in press.

Mishan, E.J. *Cost-Benefit Analysis: An Introduction*. Praeger Publishers, New York, New York, 1971a. 374 pp.

Mishan, E.J. "The Postwar Literature on Externalities: An Interpretative Essay." *Journal of Economic Literature*, 9(1):1-28, 1971b.

Moll, K.D., S. Baum, E. Capener, F.W. Dresch, and R.M. Wright. *Hazardous Wastes: A Risk-Benefit Framework Applied to Cadmium and Asbestos*. EPA-600/5-77-002, U.S. Environmental Protection Agency, Washington, D.C., 1977. 263 pp. [NTIS:PB257951]

National Academy of Engineering. *Perspectives on Benefit-Risk Decision Making*. The National Academy of Engineering, Washington, D.C., 1972. 165 pp.

National Academy of Sciences. *Considerations of Health Benefit-Cost Analysis for Activities Involving Ionizing Radiation Exposure and Alternatives*. EPA 520/4-77-003, U.S. Environmental Protection Agency, Washington, D.C., 1977. 199 pp.

National Academy of Sciences, National Academy of Engineering. *Water Quality Criteria 1972, A Report of the Committee on Water Quality Criteria*. National Academy of Sciences, Washington, D.C., 1972. 594 pp. [NTIS: PB236199]

National Oceanic and Atmospheric Administration. *Climatological Data, Annual Summary: Oregon, 1976*. Volume 82, Number 13. Environmental Data Service, National Climatic Center, Asheville, N.C., 1976.

Newcomb, R.C., and R.J. Deacon. *Geological and Subsurface Investigations: Proposed Arlington Disposal Site, Gilliam County, Oregon*. Shannon and Wilson, Inc., Portland, Oregon, 1971.

Nizard, L., and J. Tournon. "Social Perception and Social Demands in Environmental Matters." In: *Environmental Damage Costs*, Organisation for Economic Co-operation and Development, Paris, France, 1974. pp. 305-330.

Oregon Department of Fish and Wildlife. Manual for Fish Management. Oregon Department of Fish and Wildlife, Portland, Oregon, 1977. pp. 167-192.

Oregon State University. Temperature and the Water Balance for Oregon Weather Stations. Special Report 150, Agricultural Experimental Station, Oregon State University, Corvallis, Oregon, 1963.

Orem, H.M. Discharge in the Lower Columbia River Basin, 1928-1965. Geological Survey Circular 550, U.S. Geological Survey, Washington, D.C., 1968. 128 pp.

Organisation for Economic Co-operation and Development, ed. Environmental Damage Costs. Organisation for Economic Co-operation and Development, Paris, France, 1974. 332 pp.

Ott, W.R., ed. Proceedings of the EPA Conference on Environmental Modeling and Simulation. EPA 600/9-76-016, U.S. Environmental Protection Agency, Washington, D.C., 1976. 861 pp.

Ottinger, R.S., J.L. Blumenthal, D.F. DalPorto, G.I. Gruber, M.J. Santy, and C.C. Shih. Recommended Methods of Reduction, Neutralization, Recovery, or Disposal of Hazardous Waste. 16 volumes. EPA/670/2-73-053, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1973. [NTIS: PB224579 - Set]

Oxenfeldt, A.R. "Multi-Stage Approach to Pricing." Harvard Business Review, 38(4):125-133, 1960.

Pahner, P.D. A Psychological Perspective of the Nuclear Energy Controversy. RM-76-67, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976. 27 pp.

Perna, A.J. "Industrial Solid and Liquid Waste Handling and Disposal." Pollution Engineering, 9(1):148-151, 1977.

Peskin, H.M., and E.P. Seskin, eds. Cost-Benefit Analysis and Water Pollution Policy. The Urban Institute, Washington, D.C., 1975. 384 pp.

Planning Branch, Treasury Board Secretariat. Benefit-Cost Analysis Guide. Information Canada, Ottawa, Canada, 1976, 80 pp.

Porter, C.H. State Program Implementation Guide: Hazardous Waste Surveys. EPA/530/SW-160, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1975. 42 pp.

Porter, C.H. State Program Implementation Guide: Hazardous Waste Transportation Control. EPA/530/SW-512, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1976. 39 pp.

Portney, P.R. "Toxic Substance Policy and the Protection of Human Health." In: Current Issues in U.S. Environmental Policy, P.R. Portney, ed. The Johns Hopkins University Press, Baltimore, Maryland, 1978. 222 pp.

Powers, P.W. How to Dispose of Toxic Substances and Industrial Wastes. Noyes Data Corporation, Park Ridge, New Jersey, 1976. 508 pp.

Price, C.M. Welfare Economics in Theory and Practice. The Macmillan Press Ltd., London, England, 1977. 183 pp.

Provenzano, G. "Risk-Benefit Analysis and the Economics of Heavy Metals Control." In: Proceedings of the Conference on Heavy Metals in the Aquatic Environment. Vanderbilt University, Nashville, Tennessee, 1973. pp. 339-346.

Rall, D.P. "Extrapolating Environmental Toxicology, Costs and Benefits of Being Right and Wrong." A paper presented at the American Association for the Advancement of Science Meeting in New York, New York, January 26-31, 1975. [Draft]

Rappeport, M., and P. Labaw. Public Attitudes and Behavior Regarding Energy Conservation: Detailed Tabulations by U.S. Population and Population Segments. Waves 28 and 29. FEA/D-76/252, Federal Energy Administration, Washington, D.C., 1975. 42 pp. [NTIS:PB254592]

Rasmussen, N.C., director. Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants. WASH-1400, U.S. Nuclear Regulatory Commission, Washington, D.C., 1975. 207 pp. [NTIS:PB248201]

Reeder, L.R., J.H. Cobbs, J.W. Field, Jr., W.D. Finley, S.C. Vokurka, and B.N. Rolfe. Review and Assessment of Deep-Well Injection of Hazardous Waste. Volume I EPA-600/2-77-029a, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1977. 215 pp.

Rinella, J., and S. McKenzie. Elutriation Study of Willamette River Bottom Material and Willamette-Columbia River Water. Open File Report 78-28, U.S. Geological Survey, Portland, Oregon, 1977.

Rosfjord, R.E., R.B. Trattner, and P.N. Cheremisinoff. "Phenols: A Water Pollution Control Assessment." Water and Sewage Works, 123(3):96-99, 1976.

Royston, M.G., and J.C. Perkowski. "Determination of the Priorities of 'Actors' in the Framework of Environmental Management." Environmental Conservation, 2(2):137-144, 1975.

Sagan, L.A. "Human Costs of Nuclear Power." Science, 177(4048):487-493, 1972.

Sanders, G.R. "California's Hazardous Waste Management Program: VIII. Survey of Hazardous Waste Production." In: Proceedings of a National Conference About Hazardous Waste Management, E.B. Workman, ed. Vector and Waste Management Section, California State Department of Health, Sacramento, California, 1978. pp. 84-85.

Saunders, P.J.W. *The Estimation of Pollution Damage*. Manchester University Press, Manchester, England, 1976. 136 pp.

Schlaifer, R. *Analysis of Decisions Under Uncertainty*. Preliminary edition, 2 volumes. McGraw-Hill Book Company, New York, New York, 1967.

Scitovsky, T. *Welfare and Competition: The Economics of a Fully Employed Economy*. Richard D. Irwin, Inc., Chicago, Illinois, 1951. 473 pp.

SCS Engineers, Inc. *Assessment of Industrial Hazardous Waste Practices: Leather Tanning and Finishing Industry*. SW-131c, U.S. Environmental Protection Agency, Washington, D.C., 1976. 367 pp. [NTIS:PB261018]

Scurlock, A.C., A.W. Lindsey, T. Fields, Jr., and D.R. Huber. *Incineration in Hazardous Waste Management*. EPA/530/SW-141, U.S. Environmental Protection Agency, Washington, D.C., 1975. 108 pp.

Seagraves, J.A. "Industrial Waste Charges." *American Society of Civil Engineers. Journal of the Environmental Engineering Division*, 99(EE6): 873-881, 1973.

Sewell, W.R.D. "Broadening the Approach to Evaluation in Resources Management Decision-Making." *Journal of Environmental Management*, 1:33-60, 1973.

Shaver, R.G., L.C. Parker, E.F. Rissman, K.M. Slimak, and R.C. Smith. *Assessment of Industrial Hazardous Waste Practices; Inorganic Chemicals Industry*. EPA/530/SW-104c, U.S. Environmental Protection Agency, Washington, D.C., 1975. [NTIS:PB244832]

Slovic, P., and B. Fischhoff. "How Safe is Safe Enough? Determinants of Perceived and Acceptable Risk." In: *The Management of Nuclear Wastes*, L. Gould and C.A. Walker, eds. Yale University Press, in press.

Slovic, P., B. Fischhoff, and S. Lichtenstein. "Cognitive Processes and Societal Risk Taking." In: *Cognition and Social Behavior*, J.S. Carroll and J.W. Payne, eds. Lawrence Erlbaum Associates, Potomac, Maryland, 1976. pp. 165-184.

Slovic, P., H. Kunreuther, and G.F. White. "Decision Processes, Rationality, and Adjustment to Natural Hazards." In: *Natural Hazards: Local, National and Global*, G.F. White, ed. Oxford University Press, New York, New York, 1974. pp. 187-205.

Smith, D.D., and R.P. Brown. *Ocean Disposal of Barge-Delivered Liquid and Solid Wastes from U.S. Coastal Cities*. SW-19c, U.S. Environmental Protection Agency, Washington, D.C., 1971. 128 pp.

Smith, M.F., ed. *Hazardous Materials Transportation: Part 1 General Studies (Bibliography)*. NTIS/PS-76/0331, National Technical Information Service, Springfield, Virginia, 1976.

State of Oregon. Hazardous Waste Management Planning: 1972-73. Oregon Department of Environmental Quality, Portland, Oregon, 1974.

State of Oregon, Department of Economic Development. Directory of Manufacturers, 1976-1977. Department of Economic Development, Portland, Oregon, 1976. 324 pp.

State of Oregon, Department of Environmental Quality. Proposed Water Quality Management Plan for North Coast-Lower Columbia River Basin. Department of Environmental Quality, Portland, Oregon, 1976a.

State of Oregon, Department of Environmental Quality. Proposed Water Quality Management Plan for Willamette River Basin. Department of Environmental Quality, Portland, Oregon, 1976b.

State of Oregon, Department of Environmental Quality. Goals and Objectives. Department of Environmental Quality, Portland, Oregon, 1978.

Statistical Policy Division, Executive Office of the President, Office of Management and Budget. Standard Industrial Classification Manual, 1972. U.S. Government Printing Office, Washington, D.C., 1974.

Stermole, F.J. Economic Evaluation and Investment Decision Methods. Investment Evaluations Corporation, Golden, Colorado, 1974.

Sternes, G.L. Climates of the States: Oregon. U.S. Government Printing Office, Washington, D.C., 1967. 27 pp.

Stone, R., and D.E. Brown. Forecasts of the Effects of Air and Water Pollution Controls on Solid Waste Generation. EPA/670/2-74-095b, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1974. 830 pp. [NTIS:PB238219]

Stradley, M.W., G.W. Dawson, and B.W. Cone. An Evaluation of the Status of Hazardous Waste Management in Region X. EPA 910/9-76-024, U.S. Environmental Protection Agency, Seattle, Washington, 1975. 202 pp.

Swain, J.W., Jr. Assessment of Industrial Hazardous Waste Management Practices: Petroleum Rerefining Industry Study (SIC 2992). SW-144c, U.S. Environmental Protection Agency, Washington, D.C., 1976. 112 pp. [NTIS:PB272267]

Szego, G.D. The U. S. Energy Problem. InterTechnology Corporation, Warrenton, Virginia, 1971.

Talley, R.J., and O.W. Albrecht. "Preliminary Economic Analysis of Hazardous Waste Control." In-house research project, Program Element IDA312, ROAP OIADC. U.S. Environmental Protection Agency, Cincinnati, Ohio, 1974. 79 pp.

Taubman, P. "U.S. Prepares to Sue Hooker Corp. on Dumping of Hazardous Wastes." New York Times, May 21, 1979, 1, B-3.

TYPING GUIDE SHEET
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Taylor, G.A. Managerial and Engineering Economy: Economic Decision-Making. D. Van Nostrand Company, Inc., Princeton, New Jersey, 1964. 504 pp.

The Science and Public Policy Program. Energy Alternatives: A Comparative Analysis. Chapter 13 "Energy Consumption." University of Oklahoma, Norman, Oklahoma, 1975.

Tihansky, D.P., and H.V. Kibby. "A Cost-Risk-Benefit Analysis of Toxic Substances." Journal of Environmental Systems, 4(2):117-134, 1974.

U.S. Atomic Energy Commission. Comparative Risk-Cost-Benefit Study of Alternative Sources of Electrical Energy. WASH-1224, U.S. Government Printing Office, Washington, D.C., 1974.

U.S. Department of Commerce. Current Population Reports, Population Esti-Mates. Bureau of the Census Series P-26, No. 76-37, U.S. Department of Commerce, Washington, D.C., 1977.

U.S. Department of Commerce, Bureau of the Census. 1970 Census of Population. Volume 1: Characteristics of the Population. Parts 1 (Sec. 2) and 39. U.S. Department of Commerce, Washington, D.C., 1973.

U.S. Department of the Interior, Bureau of Mines. "U.S. Net Import Reliance of Selected Minerals and Metals as a Percent of Consumption in 1978." Minerals and Materials/A Monthly Survey, May 1979, p. 9.

U.S. Environmental Protection Agency. "Designation and Determination of Removability of Hazardous Substances from Water: Proposed Rules." Federal Register, 39(164):30466-30471, 1974a.

U.S. Environmental Protection Agency. Report to Congress: Disposal of Hazardous Wastes. SW-115, U.S. Environmental Protection Agency, 1974b. 120 pp.

U.S. Environmental Protection Agency. National Water Quality Inventory. EPA-440/9-74-001, U.S. Environmental Protection Agency, Washington, D.C., 1974c. 315 pp.

U.S. Environmental Protection Agency. "Effective Hazardous Waste Management (Non-Radioactive): A Position Statement." Federal Register, 41(161): 35050-35051, 1976a.

U.S. Environmental Protection Agency. "Polychlorinated Biphenyl-Containing Wastes: Disposal Procedures." Federal Register, 41(64):14134-14136, 1976b.

U.S. Environmental Protection Agency. Synopsis of Public Meetings on Hazardous Waste Management. U.S. Environmental Protection Agency, Washington, D.C., 1976c. 50 pp.

U.S. Environmental Protection Agency. Quality Criteria for Water. U.S. Environmental Protection Agency, Washington, D.C., 1976d. 270 pp.

BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
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PAGE NUMBER

U.S. Environmental Protection Agency. *Ocean Dumping in the United States--1977*. U.S. Environmental Protection Agency, Washington, D.C., 1977a.

U.S. Environmental Protection Agency. *State Decision-Makers Guide for Hazardous Waste Management*. SW-612, U.S. Environmental Protection Agency, 1977b. 109 pp.

U.S. Environmental Protection Agency. *The Report to Congress: Waste Disposal Practices and Their Effects on Ground Water*. EPA/570/9-77-001, U.S. Environmental Protection Agency, Washington, D.C., 1977c. 531 pp.

U.S. Environmental Protection Agency. *Transcript: Regional Public Meetings on the Resource Conservation and Recovery Act of 1976*. SW-20p (series), U.S. Environmental Protection Agency, 1977d.

U.S. Environmental Protection Agency. *Proposed Revisions to Ocean Dumping Criteria: Final Environmental Impact Statement*. Volume 1. U.S. Environmental Protection Agency, Washington, D.C., 1977e.

U.S. House of Representatives. *Report to the Committee on Interstate and Foreign Commerce, U.S. House of Representatives on H.R. 14496*. Report No. 94-1491, U.S. Government Printing Office, Washington, D.C., 1976.

Van Hook, R.I. *Transportation and Transformation Pathways of Hazardous Chemicals From Solid Waste Disposal*. Publication No. 1131, Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee, 1978.

Venugopal, B., and T.D. Luckey. "Toxicology of Non-Radioactive Heavy Metals and Their Salts." In: *Heavy Metal Toxicity, Safety and Hormology*, T.D. Luckey, B. Venugopal, and D. Hutcheson, eds. Academic Press, New York, New York, 1975. pp. 4-73.

Versar, Inc. *Alternatives for Hazardous Waste Management in the Inorganic Chemicals Industry*. SW-149c, U.S. Environmental Protection Agency, Washington, D.C., 1977. 288 pp. [NTIS:PB274565]

WAPORA, Inc. *Assessment of Industrial Hazardous Waste Practices: Paint and Allied Products Industry Contract Solvent Reclaiming Operations, and Factory Application of Coatings*. SW-119c, U.S. Environmental Protection Agency, 1976. 310 pp. [NTIS:PB251669]

WAPORA, Inc. *Assessment of Industrial Hazardous Waste Practices: Electronic Components Manufacturing Industry*. SW-140c, U.S. Environmental Protection Agency, Washington, D.C., 1977a. 207 pp. [NTIS:PB265532]

WAPORA, Inc. *Assessment of Industrial Hazardous Waste Practices: Special Machinery Manufacturing Industries*. SW-141c, U.S. Environmental Protection agency, Washington, D.C. 1977b. 328 pp. [NTIS:PB265981]

Wendt, D., and C. Vlek, eds. *Utility, Probability, and Human Decision Making*. D. Reidel Publishing Company, Boston, Massachusetts, 1975. 426 pp.

TYPING GUIDE SHEET
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Williams, R., R. Shamel, K. Hallock, B. Stangle, and S. Blair. *Economic Assessment of Potential Hazardous Waste Control Guidelines for the Inorganic Chemicals Industry*. EPA/530/SW-134c, U.S. Environmental Protection Agency, Washington, D.C. 1976. 320 pp.

Williamson, S.J. *A Comprehensive Survey of Hazardous Waste Generation in Oklahoma*. Ph.D. Dissertation, University of Michigan, Ann Arbor, Michigan, 1975. 349 pp.

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APPENDIX A

HAZARDOUS WASTE MANAGEMENT TECHNIQUES

This appendix describes the techniques (listed in Table 2 of the main text) that may be used for the control (including disposal) of hazardous wastes.

TECHNIQUES INVOLVING WASTE STREAM CHANGES

Process Change

In process change, the industrial process that generates the waste is changed. Substitution of a different process will normally result in generation of a different waste. The new waste could be inherently less hazardous or nonhazardous, or it could be generated in smaller quantities than before. An example of process change is the replacement of the mercury cell by a diaphragm cell for chlorine production. It appears that this changeover (all new capacity is expected to use diaphragm cells) has been caused entirely by the problems associated with wastes and emissions from the mercury cell (Saxton and Kramer, 1974).

It is not necessary to substitute a new process to change the waste streams. In some cases, process modifications such as changing the operating conditions or adding process steps (including pollution control devices) could cause the composition of the wastes to change, or could simply change the volume or concentration of the waste stream (Saxton and Kramer, 1974).

Source Reduction

With source reduction, the basic composition of a waste stream remains unchanged (except perhaps for concentration), but the quantity of the waste is reduced. This may be achieved by process modification (including the more efficient use of materials), by changes in the quality of the material inputs, or by improving procedures to reduce production spoilage, etc. (Saxton and Kramer, 1974; U.S. Environmental Protection Agency, 1976b).

Waste Separation

Waste separation involves segregating waste streams to isolate those wastes that are hazardous from those that are not, or to keep apart wastes with different hazardous properties. In the former case, the objective is to reduce the quality of hazardous waste to be handled. In the latter case, it is presupposed that the mixed waste is more difficult or costly to treat or dispose of than the same total volume of waste made up of several streams, each of which contains a smaller number of constituents. This supposition is not universally valid, as there could be antagonistic reaction between two waste streams (such as neutralization), or economies of scale could outweigh any added complexities of treating or disposing of mixed wastes.

RESOURCE RECOVERY

In resource recovery, the magnitude and composition of the waste stream is unchanged, but some of the materials or the energy content of the stream is recovered and put to beneficial use.

Materials Recovery

Recovery of materials is often carried out in conjunction with various treatment processes (U.S. Environmental Protection Agency, 1974). It does not necessarily achieve total recovery of all materials present in the waste stream. In many cases, only the more valuable or readily isolated constituents are recovered.

Energy Recovery

As an alternative to materials recovery, where the waste stream has a significant calorific value, energy recovery may be practiced. This usually involves burning the waste in some type of incinerator that is equipped with a heat exchanger to enable the heat to be captured and put to use.

WASTE TREATMENT

There are numerous treatment processes that may be used to render wastes less hazardous. Table A-1 lists some of the processes that have been identified as being appropriate to the treatment of hazardous wastes. Details of these and other treatment processes are provided in Ottinger et al. (1973, Vols. 3 and 4). Many treatment processes are specific to a limited range of waste types, and for this reason they are not discussed here.

Treatment processes do not eliminate the waste stream, but by separating out harmless components from those that are hazardous, some processes may significantly reduce the quantities of hazardous wastes that ultimately require disposal. Volume reduction by the evaporation of water or the precipitation of a hazardous sludge leaving a nonhazardous effluent are examples of such treatments. Some wastes can be rendered nonhazardous by treatment (e.g., neutralization of sulfuric acid with lime), whereas in other cases, the treatment may be a preliminary step toward disposal (e.g., a change of chemical form to reduce the waste's mobility or toxicity). Encapsulation, described below, is invariably followed by a storage or disposal process.

Encapsulation

Where a waste is not readily amenable to a detoxification treatment, it may be desirable to immobilize it in some way so that control can more readily be maintained over it. Encapsulation is often used to prevent (or at

TABLE A-1. CURRENTLY AVAILABLE HAZARDOUS WASTE TREATMENT AND DISPOSAL PROCESSES*

Process	Functions performed[a]	Types of waste[b]	Forms of waste[c]	Resource recovery capability
Physical treatment:				
Carbon sorption	VR, Se	1, 2, 4, 5	L, G	Yes
Dialysis	VR, Se	1, 2, 3, 4	L	Yes
Electrodialysis	VR, Se	1, 2, 3, 4, 6	L	Yes
Evaporation	VR, Se	1, 2, 5	L	Yes
Filtration	VR, Se	1, 2, 3, 4, 5	L, G	Yes
Flocculation/settling	VR, Se	1, 2, 3, 4, 5	L	Yes
Reverse osmosis	VR, Se	1, 2, 4, 6	L	Yes
Ammonia stripping	VR, Se	1, 2, 3, 4	L	Yes
Chemical treatment:				
Calcination	VR	1, 2, 5	L	
Ion exchange	VR, Se, De	1, 2, 3, 4, 5	L	Yes
Neutralization	De	1, 2, 3, 4	L	Yes
Oxidation	De	1, 2, 3, 4	L	
Precipitation	VR, Se	1, 2, 3, 4, 5	L	Yes
Reduction	De	1, 2	L	
Thermal treatment:				
Pyrolysis	VR, De	3, 4, 6	S, L, G	Yes
Incineration	De, Di	3, 5, 6, 7, 8	S, L, G	Yes
Detonation	Di	6, 8	S, L, G	No
Biological treatment:				
Activated sludges	De	3	L	No
Aerated lagoons	De	3	L	No
Waste stabilization ponds	De	3	L	No
Trickling filters	De	3	L	No
Soil application	De	3	L, S	No

* Source: Adapted from U.S. Environmental Protection Agency, 1974b.

[a] Functions: VR, volume reduction; Se, separation; De, detoxification; and Di, disposal.

[b] Waste types: 1, inorganic chemical without heavy metals; 2, inorganic chemical with heavy metals; 3, organic chemical without heavy metals; 4, organic chemical with heavy metals; 5, radiological; 6, biological; 7, flammable; and 8, explosive.

[c] Waste forms for which process is feasible: S, solid; L, liquid; and G, gas.

least severely retard) leaching and consequent contamination of groundwater. The technique is commonly applied to low-level radioactive wastes* (Ottinger et al., 1973, Vol.4). Hazardous wastes may be encapsulated by mixing the waste with concrete, asphalt and various plastics (such as polyethylene or polyurethane) (Fields and Lindsey, 1975). Encapsulation in glass has been proposed for high-level nuclear wastes (Energy Research and Development Administration, 1977). Often, for convenience, the waste and encapsulating medium are solidified in a steel drum, and it is sometimes possible to use off-specification resins as the encapsulating medium. The resulting mixture is typically 60 percent (by weight) of waste when mixed with a resin, but only 25 percent waste when encapsulated in cement (Ottinger et al., 1973, Vol.4).

One encapsulation technique, recently developed specifically for hazardous chemical wastes, agglomerates the waste in polybutadiene and then jackets the agglomerate in a thin layer of polyethylene. The attraction of this technique is that the waste can constitute 94 to 96 percent of the agglomerate; nevertheless, the process is still costly (Wiles and Lubowitz, 1976).

Incineration

There are three hazardous waste management techniques that fall on the borderline between treatment and disposal. These are incineration, land application, and lagooning. (The latter two are discussed later under Storage and Disposal Techniques.)

Incineration has wide potential application to hazardous wastes. It is a controlled process that uses combustion to convert the waste to a less bulky, less toxic, or less noxious material. The principal products of incineration are carbon dioxide, water, and ash; but products of primary concern (because of their deleterious effects) are compounds containing sulfur, nitrogen, and halogens. Where the combustion products from an incineration process contain undesirable compounds, secondary treatment such as afterburning, scrubbing, or filtration is required to lower concentrations to acceptable levels for atmospheric release (Ottinger et al., 1973, Vol.3). Thus incineration largely converts the waste to a harmless gaseous form, usually leaving only comparatively small quantities of ash and scrubber sludge that require disposal.

There are many different types of incinerators that can be used on industrial wastes, and different types of incinerators can handle solid, liquid, or gaseous wastes. Ottinger et al. (1973, Vol.3) and Powers (1976) provide detailed descriptions of the various types, and Scurlock et al. (1975) specifically discuss incineration for hazardous waste management.

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* In radioactive waste management, the term "high-level" is applied to wastes in which there is significant heat generation arising from radioactive decay; low-level wastes are those in which this effect is not significant. It is interesting to note that Federal regulations require the conversion of commercial high-level liquid wastes to a stable solid form preparatory to terminal storage (Energy Resources Council, 1976).

There are four technical characteristics that affect waste incineration (Ottinger et al., 1973, Vol.3). The first is combustibility, i.e., a measure of the ease with which a waste can be oxidized in a combustion environment. The next two are dwell or residence time in the combustor, and the flame temperature. These parameters affect the degree of combustion. The fourth is the turbulence present in the reaction zone of the incinerator, which is required to insure sufficient mixing of the air and the waste fuel.

Turbulence and dwell time are determined by the incinerator design, but for a given incinerator, flame temperature can be varied within certain limits. It thus follows that different incinerators will be more or less appropriate to the treatment of different wastes. Though high temperature capability incinerators with long dwell times would usually be capable of adequately treating wastes that need only low temperatures and short dwell times, such incinerators are more costly to build and operate than low temperature incinerators. Hence economic as well as technical factors influence the appropriateness of a given incinerator design for treating different wastes.

Clearly it is a prerequisite of incineration that the total materials stream entering the incinerator has sufficient calorific value to achieve the desired dwell time and temperature. If the waste cannot fulfill this requirement, it can be supplemented with a fuel. However, where the calorific value of the waste stream is itself sufficiently high, it is possible to recover energy from the waste via a heat exchanger and hence generate power, process steam, or use the surplus energy in some other useful way.

Among the most attractive candidates for incineration are organic wastes (including many pesticides) that are hazardous because of the structure of the molecule (for example, synthetic organics such as PCB's), rather than those that are hazardous because of some elements contained in the molecule (e.g., wastes containing heavy metals). Incineration may be attractive for the disposal of many ordnance wastes and for some inorganic wastes (Ottinger et al., 1973, Vol.1). Powers (1976) and Scurlock et al. (1975) provide lists of materials that may be suitable for incineration, both largely based on Ottinger et al.

A very specialized form of incineration is that of incineration at sea using purpose-designed ships (see subsequent section on ocean dumping).

STORAGE AND DISPOSAL TECHNIQUES

Land Application

Land application involves spreading or spraying of wastes over large areas of land. This technique is often used for certain nonhazardous wastes such as wastewater (Stewart, 1973; U.S. Environmental Protection Agency, 1975), sewage sludge, animal and food processing wastes, and certain industrial wastes where the waste contains materials (nutrients or soil conditioners) that should enhance crop growth (Loehr, 1977; U.S. Environmental Protection Agency, 1977b). Land application is sometimes used for some biodegradable hazardous wastes, primarily oil-related wastes* (Snyder, Rice, and Skujins, 1976; Tinnan, 1978; Lofy, 1977). The EPA is investigating the effectiveness of land application for other industrial sludges (Schomaker, 1976). Naturally, land application should be used only where there is careful control of access to the land and of its future use, and it is inappropriate for any waste that contains appreciable quantities of nonbiodegradable hazardous components.

Landfilling

The term landfilling will be used to denote any type of land burial of wastes *close to the surface* (as opposed to engineered storage, mine disposal, and deep well injection). The technique is commonly used to dispose of many types of solid wastes and sludges, but it is also used to dispose of liquids (which are usually poured onto the more solid components). There is an extensive body of literature on landfill disposal of hazardous wastes (e.g., Fields and Lindsey, 1975; Fuller, 1976; Ghassemi and Quinlivan, 1975), and on the physical effects that may arise from landfilling (e.g., Geyer, 1972; Fungaroli, 1971; Genetelli and Cirello, 1976; Hill and Zipp, 1974; Banerji, 1977; Garland and Mosher, 1975; Pavoni, Hagerty, and Lee, 1972; and Schultz, 1978). The following material is based on these and other sources.

Types of Landfills--

Open dumps--The least sophisticated form of land disposal is the open dump, in which a waste is simply deposited on the ground and left. Clearly, the open dump is an inappropriate means for disposing of any hazardous waste; it would only be acceptable (aesthetics aside) for inert wastes such as some demolition debris.

Sanitary landfills--The sanitary landfill (e.g., California Class II landfill [California State Water Resources Control Board, 1976]) provides for some environmental protection from the wastes. In a sanitary landfill, the wastes are compacted to the smallest practicable volume and covered, usually daily, with earth. These procedures minimize problems with blowing litter and with disease transmitting vectors (animals and insects). Waste compaction and a cellular construction of the sanitary landfill also reduce the possibility of fire and of its spread should one occur (U.S. Environmental Protection Agency, 1976a). Microbial decomposition of wastes results in the generation of gases (principally methane and carbon dioxide) that are generally regarded as a problem, but there have been some successful methane recovery projects (U.S. Environmental Protection Agency, 1976a).

The hydrologic conditions at a landfill are of great importance. Groundwater or infiltrating surface water moving through solid waste can produce "leachate," a solution containing dissolved and finely suspended solid matter and microbial waste products. The composition of the leachate naturally depends on the waste composition and also on the physical, chemical, and biological activities within the fill. Leaching can be minimized by landfill designs that restrict the ingress of surface water, but some authorities hold that generation of some leachate is inevitable (Brunner and Keller, 1972).

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* Waste petroleum oil has been regarded as hazardous by some authors and as nonhazardous by others. (See Jacobs Engineering Co., 1976.)

Where annual precipitation is low compared with potential evapotranspiration, over the course of a year actual evapotranspiration may balance infiltration, resulting in zero net percolation and hence negligible longrun leachate production (Fenn, Hanley, and DeGeare, 1975). This situation is characteristic of Southern California (Fenn, Hanley and DeGeare, 1975), where large quantities of liquid wastes are routinely injected into landfills apparently without producing leachate (Tinnan, 1978). Nevertheless, even in arid areas where leaching is expected to be negligible, a good landfill design will attempt to restrict the potential environmental damage that could be caused by a leachate. In areas with less favorable climates (e.g., Cincinnati, Ohio, or Orlando, Florida) (Fenn, Hanley, and DeGeare, 1975), where leachate production is inevitable (unless of course the surface or near-surface of the landfill is rendered impervious), some means of isolating the leachate from groundwater is essential to provide complete environmental protection.

Chemical landfills--The chemical landfill (e.g., California Class I landfill [California State Water Resources Control Board, 1976]) is designed to accept industrial wastes that may include hazardous wastes. In a chemical landfill particular attention is paid to minimizing the potential for leachate contamination of water sources. Thus, a chemical landfill should be designed so that any surface water runoff is collected and treated, and so that there is virtually no chance that leachate will percolate into any aquifer.

Isolation of Landfill Contents from the Environment--

Three principal means are available to minimize the probability that landfill leachate can contaminate groundwater: Geologic isolation, landfill liners, and leachate collection systems. Note that in this report, the term "leachate" will be used to denote any aqueous-based liquid that may emanate from a landfill or lagoon. Thus, leachate may be generated either by the interaction of environmental water (precipitation, surface water or groundwater) with an essentially solid waste as described above, or it may be the aqueous component of a liquid or semi-liquid waste that is sufficiently mobile to be able to leave the landfill or lagoon. With regard to groundwater contamination, the primary concern is protection of usable aquifers, not of small lenses of perched groundwater that are not significant as potential water supply sources.

Geologic isolation--Geologic isolation involves selecting the landfill (or lagoon) site such that there is no natural hydrologic interconnection between the fill and aquifer. This condition may be fulfilled if the permeability of the soil or rock that separates the landfill from any aquifer is sufficiently low (i.e., essentially zero). This approach is favored by the California Class I landfill regulations, which specify geologic isolation for vertical water movement, but which permit liners to control lateral movement.

A modification of this approach is found in arid areas, where natural leachate generation (i.e., that resulting from the infiltration of external sources of water) plus any liquid emanating from the waste, is expected to be slight. In this case, provided the vertical distance to groundwater is sufficiently large, there is less concern over the permeability of the intervening strata on the assumption that the total quantity of leachate generated will be insufficiently great to percolate down to the groundwater.

Many soils have the capacity to attenuate leachates that pass through them or to render these leachates less hazardous (see Roulier, 1977; Farquhar, 1977; Schultz, 1978). This can be regarded as a form of treatment, but if the mechanism is that of ion exchange (as opposed to microbial action), the treatment capacity, although often very large, will not be unlimited, since there is no regeneration mechanism.

Landfill liners--Liners are usually composed of either a layer of impervious soil (such as clay), asphalt, or a polymeric membrane (Haxo, Haxo and White, 1977; Geswein, 1975). They may be used to replace or supplement geologic isolation to provide separation from groundwater. For example, a liner could be used to provide a seal over a faulted or fissured zone of an otherwise impervious stratum, or it could be used to control the lateral movement of leachate where geologic isolation is effective in the vertical direction. Liner materials could also be used to cap a completed landfill to prevent the ingress of surface and near-surface waters. There is one important difference between complete geologic isolation and the use of a liner; because of the comparative thinness of a liner, in most cases it is probably only a matter of time (in the context of perpetual care) before the leachate penetrates the liner.

Leachate collection systems--Where significant leachate production is expected, something must be done with the leachate. Leachate collection systems can be used to divert the leachate into treatment or holding tanks. Even if a collection system does not collect all the leachate, the quantity that is available to threaten aquifers is reduced, leading to a potentially more secure operation. Collection systems often are made up of a porous medium (e.g., loam or gravel) that permits the leachate to migrate into headers for collection and treatment. The porous medium is placed on top of a liner or other impervious layer (Fields and Lindsey, 1975). Of course, the collected leachate will usually constitute an additional hazardous waste that must be appropriately managed (e.g., by precipitating a sludge that is returned to some form of land disposal).

Mine Disposal

Disposal of hazardous wastes in underground mines has been proposed for both radioactive and nonradioactive wastes. The attraction of the approach lies in the high degree of environmental protection that can be provided by such storage because of the impermeability and geological stability of the candidate formations. The material of greatest interest is salt (both bedded and domed formations), followed by gypsum and potash. Shale, limestone, and granite formations have also been considered (Stone et al., 1975). The most widely accepted concept is to place the solidified containerized wastes in disused room and pillar salt mines (Kown et al., 1977). This means of disposal has substantially greater direct economic costs than landfilling, especially if it is necessary to construct a mine for this purpose rather than to adapt an abandoned mine. A special feature of this approach is that provision can be made for future retrieval of the wastes.

Lagooning

Lagooning involves placing liquid wastes in open ponds and may incorporate some of the chemical or biological treatment processes listed in Table A-1, such as biological oxidation by means of aerated lagoons or oxidation ponds (Ottinger et al., 1973, Vol.4). Where the evaporation rate is sufficiently high (i.e., where open-pan evaporation significantly exceeds precipitation), lagooning really constitutes a treatment process for volume reduction. In other cases, it is more appropriately regarded as a storage technique. In either case, quantities of sludges and/or solids will ultimately require disposal.

Since the contents of a lagoon are at least part liquid, protection of the groundwater below and adjacent to the lagoon is of particular significance. The techniques that can be used to achieve this have already been discussed under landfilling. It is also important to insure that the lagoon does not overflow and thereby contaminate surface waters, and that birds are protected by being discouraged from landing on the surface.

Deep Well Injection

Deep well injection involves disposing of liquid wastes by pumping them into deep wells, whereby the wastes become contained within the interstices of the rock. This procedure has been used for decades to dispose of oil field brines, and it is an accepted means of disposal for such wastes (Reeder et al., 1977). WAPORA has catalogued all the wells used for injection of industrial wastes (excluding oil field brines) in the United States (WAPORA, Inc., 1974). Over half the wells have been constructed in Texas and Louisiana, and 68 percent serve SIC 28 and 29 (chemical and allied products and petroleum refining industries).

The term "deep well" may be something of a misnomer, as the concept merely involves disposing of the waste in formations that are below usable aquifers. Nevertheless, 90 percent of the 278 U.S. wells used for injecting industrial and municipal wastes identified by WAPORA, Inc. (1974) were more than 305 m deep.

In virtually all deep wells used for industrial waste disposal, wastes are injected into sands, sandstones, or carbonates (WAPORA, Inc., 1974). Suitable strata almost invariably contain saline groundwater, hence injected wastes will displace and/or mix with this groundwater. Because any solid matter will plug the host rock pores, it follows that only filtered liquids that are compatible with the host fluid (i.e., do not form precipitates) can be injected. Rock fracturing to increase permeability is feasible under certain circumstances (Reeder et al., 1977). There is an extensive body of literature on deep well waste injection (Rima, Chase, and Meyers, 1971; Cook, 1972), and the topic has been well summarized by Warner and Orcutt (1973).

Ocean Dumping

Ocean dumping has been a common means of disposal of unwanted materials for centuries (Miller, 1973). Although the quantities involved have been dominated by dredge spoils, significant quantities of sewage sludge and industrial wastes were dumped in the 1960's, together with smaller quantities of construction and demolition debris, solid waste, explosives, and radioactive wastes (Council on Environmental Quality, 1970).

The intent of the Marine Protection, Research and Sanctuaries Act of 1972 is to strictly limit the ocean dumping of any material that could adversely affect the marine environment (U.S. Environmental Protection Agency, 1977a); and in recent years, the quantities of industrial wastes that have been dumped off the U.S. coast have declined significantly.

The three basic techniques for the ocean disposal of wastes are:

1. Bulk disposal of liquid or sludge/slurry wastes using specially constructed barges;
2. Scuttling vessels filled with wastes (usually obsolete munitions);
3. The sinking at sea of containerized wastes (e.g., in 0.2 m^3 [55-gal] drums) that are carried as deck cargo on merchant vessels.

Depending on the details of the techniques and the waste involved, the ocean may be used as a reacting or neutralizing medium, as a diluent, as a cushioning medium (for detonated explosives), or for protective isolation (Ottinger et al., 1973, Vol.3). In general, ocean dumping sites avoid estuarine locations, and though some barged disposal takes place in comparatively shallow water, containerized wastes and vessels are scuttled in the deep sea (Smith and Brown, 1971).

The type of waste strongly affects its physical disposition. Hazardous wastes that would float are clearly unacceptable for ocean disposal. Wastes that are considerably denser than seawater fall to the ocean floor, and any dispersion that occurs will be through ocean bottom processes. Most aqueous-based wastes, on the other hand, have densities similar to seawater and can diffuse widely (Ocean Disposal Study Steering Committee, 1976). Clark et al. (1971) review these physical diffusion processes and also discuss disposal economics.

A variety of data on the practice and impacts of ocean disposal may be found in the literature (Council on Environmental Quality, 1970; Ocean Disposal Study Steering Committee, 1976; Smith and Brown, 1971; Reed, 1975; Interstate Electronics Corporation, 1973).

Incinerator ships can be considered as a special case of ocean dumping. While the objective of incineration is to thermally degrade the hazardous material, it is almost inevitable that a small proportion of the waste will escape degradation. Furthermore, the products of degradation may themselves be hazardous and require some form of disposal. Thus by conducting incineration at sea, the wastes emitted from the incinerator are widely dispersed, which may be more environmentally acceptable than using similar incineration equipment on land. The technique has been in use in Europe since 1968 (Powers, 1976).

Incineration of U.S. organochlorine wastes has been conducted on an experimental basis in the Gulf of Mexico using the Dutch incinerator ship M/T Vulcanus. The incinerators achieved upwards of 99.9 percent oxidation of the wastes, and the resulting emissions (which included hydrogen chloride) were discharged to the atmosphere without scrubbing (Wastler et al., 1975). Had a similar operation been performed on land, scrubbing would doubtless have been required to provide environmental protection from the hydrogen chloride (see, Maritime Administration, no date).

Engineered Storage

As already indicated, most forms of disposal amount to storage, as it is not possible to eliminate matter. However, the term "engineered storage" is usually reserved for placement of wastes into manmade structures (as opposed to burial in the ground, for example).

This technique has been advocated largely for high-level radioactive wastes and for other wastes for which no satisfactory alternative means of disposal exists. The intention is that the wastes are stored under very carefully controlled conditions until a safe means of disposal can be found; for this reason, provision for easy retrieval must be an integral part of the design (U.S. Environmental Protection Agency, 1974).

Other Techniques

Disposal into space has been proposed for certain radioactive wastes and represents a unique concept. As far as the author is aware, it has not been considered for nonnuclear wastes, doubtless because of its extremely high direct cost, which is in excess of $2,000 per kg of waste including containers (Battelle Memorial Institute, Pacific Northwest Laboratories, 1976).

All other techniques that have been proposed appear to constitute subcategories or special cases of those discussed above. For example, thermal treatment can be split into four principal subcategories, which are (in descending order of control maintained over the waste and its decomposition products): Pyrolysis, incineration, open burning, and detonation. At least some of these subcategories are capable of further division, as already illustrated for incineration. Even ice sheet disposal, which has been proposed for some radioactive wastes (Battelle Memorial Institute, Pacific Northwest Laboratories, 1976), can be regarded as a special case of land disposal, since many of its features and potential threats to the environment are similar to the more conventional forms of land disposal already discussed.

REFERENCES

Banerji, S.K., ed. Management of Gas and Leachate in Landfills. EPA-600/9-77-026, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1977. 288 pp.

Battelle Memorial Institute, Pacific Northwest Laboratories. Alternatives for Managing Wastes From Reactors and Post-Fission Operations in the LWR Fuel Cycle. Volume 4: Alternatives for Waste Isolation and Disposal. ERDA-76-43, Energy Research and Development Administration, 1976.

Brunner, D.R. and D.J. Keller. Sanitary Landfill Design and Operation. SW-65ts, U.S. Environmental Protection Agency, Washington, D.C., 1972. 59 pp.

California State Water Resources Control Board. Waste Discharge Requirements for Nonsewerable Waste Disposal to Land: Disposal Site Design and Operation Information. California State Water Resources Control Board, Sacramento, California, 1976. 60 pp.

Clark, B.D., W.F. Rittal, D.J. Baumgartner, and K.V. Byram. The Barged Ocean Disposal of Wastes: A Review of Current Practice and Methods of Evaluation. U.S. Environmental Protection Agency, Corvallis, Oregon, 1971. 119 pp. [NTIS: PB204868]

Cook, T.D., ed. Underground Waste Management and Environmental Implications. Memoir 18, The American Association of Petroleum Geologists, Tulsa, Oklahoma, 1972.

Council on Environmental Quality. Ocean Dumping: A National Policy. U.S. Government Printing Office, Washington, D.C., 1970. 45 pp.

Energy Research and Development Administration. Alternatives for Long-Term Management of Defense High-Level Radioactive Waste, Savannah River Plant, Aiken, South Carolina. Volume 1. ERDA 77-42/1, Energy Research and Development Administration, Washington, D.C., 1977.

Energy Resources Council. Management of Commercial Radioactive Nuclear Wastes: A Status Report. FEA/A-76/295, Federal Energy Administration, Washington, D.C., 1976. 18 pp.

Farquhar, G.J. "Leachate Treatment by Soil Methods." In: Management of Gas and Leachate in Landfills, S.K. Banerji, ed. EPA-600/9-77-026, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1977. pp. 187-207.

Fenn, D.G., K.J. Hanley, and T.V. DeGeare. Use of the Water Balance Method for Predicting Leachate Generation from Solid Waste Disposal Sites. EPA/530/SW-168, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1975. 40 pp.

Fields, T., Jr., and A.W. Lindsey. Landfill Disposal of Hazardous Wastes: A Review of Literature and Known Approaches. EPA/530/SW-165, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1975. 36 pp.

Fuller, W.H., ed. Residual Management by Land Disposal: Proceedings of the Hazardous Waste Research Symposium. EPA-600/9-76-015, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1976. 280 pp.

Fungaroli, A.A. Pollution of Subsurface Water by Sanitary Landfills. 3 volumes. SW-12RG, U.S. Environmental Protection Agency, Rockville, Maryland, 1971.

Garland, G.A., and D.C. Mosher. "Leachate Effects of Improper Land Disposal." Waste Age, 5(11):42-48, 1975.

Genetelli, E.J., and J.Cirello, eds. Gas and Leachate From Landfills: Formation, Collection and Treatment. EPA/600/9-76-004, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1976. 196 pp.

Geswein, A.J. Liners For Land Disposal Sites: An Assessment. EPA/530/SW-137, U.S. Environmental Protection Agency, 1975. 66 pp.

Geyer, J.A. Landfill Decomposition Gases. An Annotated Bibliography. SW-72-1-1, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1972. 36 pp. [NTIS: PB213487]

Ghassemi, M., and S. Quinlivan. A Study of Selected Landfills Designed as Pesticide Disposal Sites. EPA/530/SW-114c, U.S. Environmental Protection Agency, Washington, D.C., 1975. 140 pp. [NTIS: PB250717]

Haxo, H.E., Jr., R.S. Haxo, and R.M. White. Liner Materials Exposed to Hazardous and Toxic Sludges: First Interim Report. EPA-600/2-77-081, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1977. 73 pp.

Hill, D.M., and R. Zipp. Ground Water Quality and Solid Waste Management: A Selective Bibliography. State of California, The Resources Agency, Department of Water Resources, Central District, 1974. 59 pp.

Interstate Electronics Corporation. Bibliography on Ocean Waste Disposal. Contract No. 68-01-0796, U.S. Environmental Protection Agency, Washington, D.C., 1973.

Jacobs Engineering Co., Inc. Assessment of Industrial Hazardous Waste Practices, Petroleum Refining. SW-129c, U.S. Environmental Protection Agency, Washington, D.C., 1976. [NTIS: PB259097]

Kown, B.T., R.A. Stenzel, J.A. Hepper, J.D. Ruby, and R.T. Milligan. Cost Assessment for the Emplacement of Hazardous Materials in a Salt Mine. EPA-600/2-77-215, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1977. 128 pp.

Loehr, R.C., ed. *Land as a Waste Management Alternative: Proceedings of the 1976 Cornell Agricultural Waste Management Conference*. Ann Arbor Science Publishers Inc., Ann Arbor, Michigan, 1977. 810 pp.

Lofy, R.J. "Petroleum Refinery Solid Waste Disposal Practices." In: *Proceedings of a National Conference about Hazardous Waste Management*, E.B. Workman, ed. Vector and Waste Management Section, California State Department of Health, Sacramento, California, 1978. pp. 161-165.

Maritime Administration. *Draft Environmental Impact Statement - Chemical Waste Incinerator Ship Project* (Volume 1 of 2 - Environmental Analysis and Appendices I, II and III). MA-EIS-7302-76-08D, U.S. Department of Commerce, Washington, D.C., no date. 236 pp. [NTIS: PB246727]

Miller, H.C. "Ocean Dumping--Prelude and Fugue." *Journal of Maritime Law and Commerce*, 5(1):51-75, 1973.

Ocean Disposal Study Steering Committee. *Disposal in the Marine Environment: An Oceanographic Assessment*. National Academy of Sciences, Washington, D.C., 1976. 85 pp.

Ottinger, R.S., J.L. Blumenthal, D.F. DalPorto, G.I. Gruber, M.J. Santy, and C.C. Shih. *Recommended Methods of Reduction, Neutralization, Recovery, or Disposal of Hazardous Waste*. 16 volumes. EPA-670-2-73-053, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1973. [NTIS: PB224579-Set]

Pavoni, J.L., D.J. Hagerty, and R.E. Lee. "Environmental Impact Evaluation of Hazardous Waste Disposal in Land." *Water Resources Bulletin*, 8(6): 1091-1107, 1972.

Powers, P.W. *How to Dispose of Toxic Substances and Industrial Wastes*. Noyes Data Corporation, Park Ridge, New Jersey, 1976. 508 pp.

Reed, A.W. *Ocean Waste Disposal Practices*. Noyes Data Corporation, Park Ridge, New Jersey, 1975. 346 pp.

Reeder, L.R., J.H. Cobbs, J.W. Field, Jr., W.D. Finley, S.C. Vokurka, and B.N. Rolfe. *Review and Assessment of Deep-Well Injection of Hazardous Waste. Volume I*. EPA-600/2-77-029a, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1977. 215 pp.

Rima, D.R., E.B. Chase, and B.M. Myers. *Subsurface Waste Disposal by Means of Wells--A Selective Annotated Bibliography*. U.S. Geological Survey Water Supply Paper 2020, U.S. Government Printing Office, Washington, D.C., 1971. 309 pp.

Roulier, M.H. "Attenuation of Leachate Pollutants by Soils." In: *Management of Gas and Leachate in Landfills*, S.K. Banerji, ed. EPA-600/9-77-026, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1977. pp. 127-138.

Saxton, J.C., and M. Kramer. Industrial Chemicals Solid Waste Generation: The Significance of Process Change, Resource Recovery, and Improved Disposal. EPA-670/2-74-078, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1974. 154 pp.

Schomaker, N.B. "Current Research on Land Disposal of Hazardous Wastes." In: Residual Management by Land Disposal: Proceedings of the Hazardous Waste Research Symposium, W.H. Fuller, ed. EPA-600/9-76-015, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1976. pp. 1-13.

Schultz, D.W., ed. Land Disposal of Hazardous Wastes: Proceedings of the Fourth Annual Research Symposium. EPA-600/9-78-016, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1978.

Scurlock, A.C., A.W. Lindsey, T. Fields, Jr., and D.R. Huber. Incineration in Hazardous Waste Management. EPA/530/SW-141, U.S. Environmental Protection Agency, 1975. 108 pp.

Smith, D.D., and R.P. Brown. Ocean Disposal of Barge-Delivered Liquid and Solid Wastes from U.S. Coastal Cities. SW-19c, U.S. Environmental Protection Agency, 1971. 128 pp.

Snyder, H.J., Jr., G.B. Rice, and J.J. Skujins. "Disposal of Waste Oil Re-refining Residues by Land Farming." In: Residual Management by Land Disposal: Proceedings of the Hazardous Waste Research Symposium, W.H. Fuller, ed. EPA-600/9-76-015, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1976. pp. 195-205.

Stewart, J.M., ed. Proceedings: Workshop on Land Disposal of Wastewaters. Water Resources Research Institute, Report No. 91, UNC-WRRI-73-91, University of North Carolina, Water Resources Research Institute, 1973. 118 pp.

Stone, R.B., P.L. Aamodt, M.R. Engler, and P. Madden. Evaluation of Hazardous Wastes Emplacement in Mined Openings. EPA-600/2-75-040, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1975. 568 pp. [NTIS: PB250701]

Tinnan, L.M. "Methods Presently Used to Treat and Dispose of Hazardous Wastes in Southern California: IV. Methods Used in Southern California." In: Proceedings of a National Conference about Hazardous Waste Management, E.B. Workman, ed. Vector and Waste Management Section, California State Department of Health, Sacramento, California, 1978. pp. 45-46.

U.S. Environmental Protection Agency. Report to Congress: Disposal of Hazardous Wastes. SW-115, U.S. Environmental Protection Agency, 1974. 120 pp.

U.S. Environmental Protection Agency. Evaluation of Land Application Systems. EPA-430/9-75-001, U.S. Environmental Protection Agency, Washington, D.C., 1975. 204 pp.

U.S. Environmental Protection Agency. Decision-Makers Guide in Solid Waste Management. SW-500, U.S. Environmental Protection Agency, 1976a. 158 pp.

U.S. Environmental Protection Agency. "Effective Hazardous Waste Management (Non-Radioactive): A Position Statement." Federal Register, 41(161): 35050-35051, 1976b.

U.S. Environmental Protection Agency. Ocean Dumping in the United States--1977. U.S. Environmental Protection Agency, Washington, D.C., 1977a.

U.S. Environmental Protection Agency. The Report to Congress: Waste Disposal Practices and Their Effects on Ground Water. EPA-570/9-77-001, U.S. Environmental Protection Agency, Washington, D.C., 1977b. 531 pp.

WAPORA, Inc. Compilation of Industrial and Municipal Injection Wells in the United States. Volume I. EPA-520/9-74-020, U.S. Environmental Protection Agency, 1974.

Warner, D.L., and D.H. Orcutt. "Industrial Wastewater-Injection Wells in United States--Status of Use and Regulation, 1973." In: Preprints of papers presented at the Second International Symposium on Underground Waste Management and Artificial Recharge. Volume 2. J. Braunstein, ed. The George Banta Company, Inc., Menasha, Wisconsin, 1973. pp. 687-697.

Wastler, T.A., C.K. Offutt, C.K. Fitzsimmons, and P.E. Des Rosiers. Disposal of Organochlorine Wastes by Incineration at Sea. EPA-430/9-75-014, U.S. Environmental Protection Agency, Washington, D.C., 1975. 238 pp.

Wiles, C.C., and H.R. Lubowitz. "A Polymeric Cementing and Encapsulating Process for Managing Hazardous Waste." In: Residual Management by Land Disposal: Proceedings of the Hazardous Waste Research Symposium, W.H. Fuller, ed. EPA-600/9-76-015, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1976. pp. 139-150.

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APPENDIX B

ENVIRONMENTAL THREATS ASSOCIATED WITH HAZARDOUS WASTE MANAGEMENT TECHNIQUES

This appendix discusses some of the more important threats to man and the environment associated with hazardous waste management techniques.

THE NATURE OF HAZARDOUS WASTE THREATS

This section characterizes environmental threats posed by hazardous waste management techniques, commencing with threats that are applicable to many techniques, followed by the threats that are more specific in nature. In some cases, models or numerical data are available and can be used to provide estimates of the magnitude of the impacts, while in others, only descriptive scenarios are feasible. (Ott [1976] provides much information on environmental modeling techniques.) Probabilities that threats will occur are largely discussed later in this appendix, and the economic implications of the threats are discussed in Appendix C.

In-plant Accidents and Other Events

Within the manufacturing plant that generates the waste, a threat of some sort of accident or operational failure exists regardless of the waste management technique employed, unless all hazardous wastes are eliminated. However, the probability of occurrence and potential consequences may change with different control techniques. In an assessment of hazardous waste management alternatives (as opposed, for example, to examining the total costs and benefits of using a particular substance or manufacturing a particular product), it is only differential effects between alternative approaches that are of interest. Thus where a given waste (type, form, and quantity) is generated and shipped out of the plant without treatment for disposal or resource recovery, the probability and consequences of in-plant, waste-related accidents should be constant. However, where the waste stream itself changes--arising from process change or in-plant resource recovery operations--the probability, nature and consequence of in-plant accidents may vary. Likewise, the probability of in-plant accidents may change if the waste is subjected to an onsite treatment process before disposal.

The location (on or off the manufacturing site) of final disposal need not affect the frequency of occurrence of in-plant accidents, as accidents and other events associated with onsite disposal can be regarded as disposal threats rather than in-plant accidents. However, wastes are often stored before disposal--sometimes for long periods while waiting for an appropriate

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disposal method to be developed--and accidents arising from such storage can conveniently be included with in-plant accidents.

Though it is not difficult to generate scenarios for in-plant accidents associated with hazardous wastes, statistical data on such accidents are not generally available. The problem is that official industrial accident data (e.g., data on occupational illness and injury at manufacturing plants [U.S. Department of Labor, 1976]) do not usually differentiate beween those involving wastes and those involving other materials. Data are available on accidents and illnesses arising in SIC 495, Sanitary Services, which could encompass various disposal techniques (U.S. Department of Labor, 1976). However, these data are likely to be dominated by accidents in sewage works and in regular refuse collection. Buckley and Wiener (1978) have collected numerous data from insurance loss records, newspaper reports, and other sources that provide a useful indication of the causes and size distribution of hazardous material spills; but in many cases, it is not known whether or not the material was a waste.

Possible in-plant accident scenarios that can directly affect man will largely be related to spills and emission of materials that can cause acute human poisoning by absorption through the skin or inhalation (Munn, 1975). Poor plant practices could also result in systematic exposure leading to chronic poisoning. Chronic poisoning from industrial chemicals is considered by some authors to be a far greater threat to workers than acute poisoning (Munn, 1975), but statistical data are sparse, as in many cases it is difficult to relate chronic illnesses to industrial exposure. (Some clear-cut exceptions--such as black lung disease and asbestosis--arise where a substantial industrial sector is exposed to a single disease-causing material.)

Environmental damage and indirect threats to man could arise from failure or overflow of storage tanks, operating lagoons, containment dikes, and sumps, which could result in destruction of vegetation and a variety of surface and groundwater pollution problems. Where wastes are flammable or highly reactive, fires and explosions could occur. Methodologies for calculating the physical effects and probabilities of many of these incidents for specific materials are presented by Arthur D. Little, Inc. (1975).

Transportation Accidents

Comparatively good data are available on the nature and frequency of transportation accidents. Many of these specifically address hazardous materials (Booz, Allen, and Hamilton, 1970; National Academy of Sciences, 1976; Arthur D. Little, Inc., 1974; Jones et al., 1973). Typical hazardous material spill frequency and size data are given in Table B-1. Unfortunately, the accident probability statistics show considerable diversity, depending on source and coverage.

Some authors emphasize the likely outcome of transportation accidents (Arthur D. Little, Inc., 1975; Jones et al., 1973; Angell and Kalelkar, 1974), sometimes indirectly via studies of the control of hazardous material spills (Dawson, Shuckrow, and Swift, 1970; Anon., 1974). The emphasis in

TABLE B-1. SELECTED TRANSPORT ACCIDENT STATISTICS

	Events per billion kilometers		
Source and type of cargo	**Truck**	**Rail**	**Water (barge)**
Arthur D. Little, Inc.[a]			
Hazardous chemicals			261[b]
Flammable liquids		144[c]	
Corrosive liquids		186[c]	
Tank trucks (involving cargo loss)	17[d]		
Booz, Allen, and Hamilton[e]			
Hazardous materials (projections to 1980)	1,119	20	$0.68/10^6$ tonne-km
Jones et al.[f]			
Hazardous materials	1,057[g]	8-11[h]	
Autos, all accidents	2,140-12,500[i]		
Arthur D. Little, Inc.[j]	22[k]	12[l]	

[a] Arthur D. Little, Inc., 1975:29,30.

[b] Typical large capacities are up to 1,816 tonnes (2,000 short tons). Average spill size is approximately 48,450 liters.

[c] For 1965-70.

[d] For 1968-72. Typical tank capacities range from 22,700 to 37,850 liters (6,000 to 10,000 gal). The average spill size is about 11,350 liters.

[e] Booz, Allen, and Hamilton, 1970:15.

[f] Jones et al., 1973:99-102.

[g] Based on FHA data for large carriers.

[h] For 1960-68; data may be conservative.

[i] Based on a variety of sources. (It is claimed that vehicle size does not affect accident frequency.)

[j] Arthur D. Little, Inc., 1973, Vol.II:111.

[k] For tank trucks.

[l] For railroad cars, based on data from Association of American Railroads and Federal Railroad Administration.

most of these studies is on damage to human life and to property, especially through the mechanisms of fire and explosion.

Very few authors attempt to analyze the impact of transportation accidents on flora or fauna (nonhuman). In a paper that addresses choices in risk situations via the determination of a decisionmaker's utility functions, Kalelkar, Partridge, and Brooks (1974) use a 13-point scale to indicate the severity of land-based environmental impacts that are expected to arise from typical accidents during the transportation of specified hazardous materials. This scale, which is used in conjunction with the area affected, is as follows:

1. No effect;
2. Residual surface accumulation of harmless material such as sugar or grain;
3. Aesthetic pollution (odor-vapors);
4. Residual surface accumulation of removable material such as oil (requires more costly measures of abatement);
5. Persistent leaf damage (spotting, discoloration), but foliage remains edible for wildlife;
6. Persistent leaf damage (loss of foliage), but new growth in following year;
7. Foliage remains poisonous to animals (indirect cause of some deaths upon ingestion);
8. Animals become more susceptible to predators because of direct exposure to chemicals and a resulting physical debilitation;
9. Death to most smaller animals (consumers);
10. Short term (one season) loss of producers (foliage) with migration of specific consumers (those who eat the specific producer), but eventual reforestation;
11. Death to producer (vegetation) and migration of consumer (animals);
12. Death to consumers and producers;
13. Sterilization of total environment (decomposers, consumers, producers) with no potential for reforestation or immigration of species. (Kalelkar, Partridge, and Brooks, 1974:340)

Spills Into Water

Dawson and co-workers have addressed the problem of spills of hazardous materials (from both transportation accidents and stationary sources) that reach surface watercourses (Dawson, Stradley, and Shuckrow, 1975, Vols.II and IV; Dawson and Stradley, 1975). Their approach determines the proportion of annual production of each material of interest that is spilled, and follows this through to provide an estimate of spills that result in "substantial damage" to aquatic systems. The estimates of damage are based on simple modeling of the dilution and transport processes, and they employ toxicological data for typical fish receptors (Dawson and Stradley, 1975). Figure B-1 illustrates this process for sulfuric acid; however, the proportion of production spilled (0.0025 percent) is believed to be typical of many hazardous materials (Dawson and Stradley, 1975), and the distribution among the four categories of spills and the proportions of these spills that reach the water are in fact based on aggregate data (Dawson and Stradley, 1975). However, the proportion of the material spilled that causes substantial damage is expected to depend on the material. Note that the data shown in Figure B-1 appear to mask the importance of stationary sources in causing aquatic damage. Tables B-2, B-3, and B-4 present fish kill data from the past decade. Of kills attributed to industrial releases and transport accidents, only 8 percent of the game fish and 28 percent of all fish were killed as a result of transport accidents (Table B-4).

Treatment Process Failures

One class of threat arises from the possibility that a waste may be subjected to some treatment process (e.g., detoxification, neutralization, immobilization), but that the treatment process does not work as intended. The result could be a waste that was more hazardous than anticipated. The variability in composition of waste streams makes this a real possibility, although it does not appear to be a problem that has attracted much attention.

Some treatment processes are comparatively straightforward and easily checked. For example, simple acid/base neutralization is controlled by checking pH, so only a measurement error is likely to lead to an environmental threat. On the other hand, biological processes are sensitive to waste composition (Battelle Memorial Institute, Pacific Northwest Laboratories, 1974) and where used, they might be rendered inoperative by the presence of undetected materials in the waste stream. Worse, inorganic mercury, which is comparatively nontoxic in monovalent form (Venugopal and Luckey, 1975), may be converted to the highly toxic methyl mercury (organic form) by anaerobic bacterial action (U.S. Environmental Protection Agency, 1974); hence it is not inconceivable that under adverse conditions, a waste containing traces of mercury could become more hazardous after treatment.

A more typical treatment threat scenario than that discussed above would be the failure of an incinerator to achieve the dwell time or temperature necessary to fully degrade the waste. This might arise because the incineration parameters necessary to degrade the waste of interest are not adequately known. The scrubber system could also fail. Though it is possible to make measurements to detect virtually any of the failures that can be envisaged, in practice, such measurements may not be made, or defective equipment may not be shut down.

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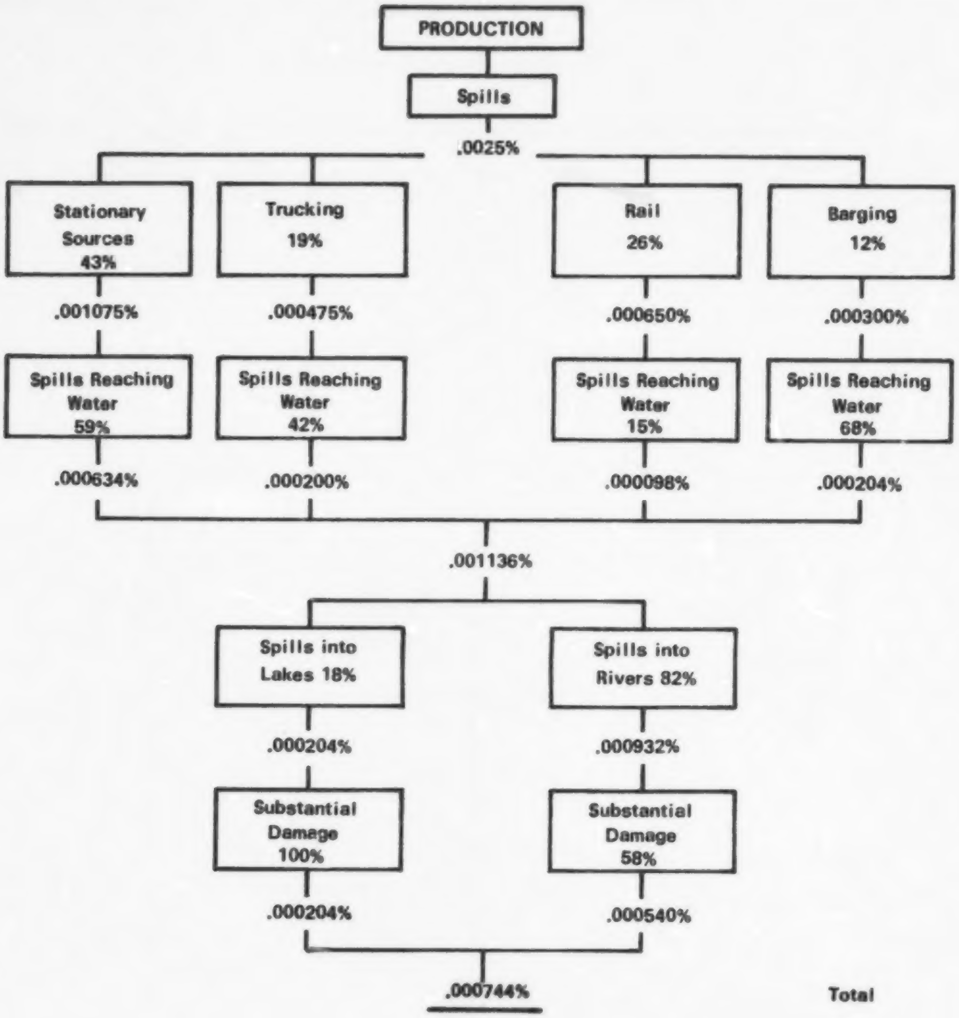
PRODUCTION
Spills
.0025%
Stationary Sources 43%
Trucking 19%
Rail 26%
Barging 12%
.001075%
.000475%
.000650%
.000300%
Spills Reaching Water 59%
Spills Reaching Water 42%
Spills Reaching Water 15%
Spills Reaching Water 68%
.000634%
.000200%
.000098%
.000204%
.001136%
Spills into Lakes 18%
Spills into Rivers 82%
.000204%
.000932%
Substantial Damage 100%
Substantial Damage 58%
.000204%
.000540%
.000744%
Total

Figure B-1. Process for estimating damages caused by spills (sulfuric acid) into water.

Source: Dawson and Stradley, 1975:25. Reproduced by permission of the American Institute of Chemical Engineers.

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TABLE B-2. SUMMARY OF POLLUTION-CAUSED FISH KILLS FOR THE UNITED STATES, 1960-1975*

	1960[2]		1961		1962		1963		1964		1965		1966		1967		1968		1969		1970		1971		1972		1973		1974		1975	
Number of States responding	38		45		37		38		40		44		46		40		42		45		45		46		50		50		50		50	
Number of reports	289		413		421		442		590		625		532		454		542		594		635		860		760		749		721		624	
Reports which state number of fish killed	151		265		246		304		470		520		453		364		469		492		563		759		697		703		648		543	
Total reported number of fish killed	6,035,000		14,910,000		44,001,000		6,937,000		22,914,000		12,140,000		9,614,000		11,291,000		15,815,000		41,166,000		22,290,000		73,670,000		17,717,000		37,814,000		19,052,000		16,111,210	
Average size of kill[1]	2,925		6,535		5,710		7,775		5,490		4,310		5,620		6,460		6,015		5,860		6,412		6,154		4,639		5,527		6,532		3,879	
Largest kill reported	5,000,000		5,387,000		3,180,000		2,000,000		7,887,000		3,000,000		1,000,000		6,549,000		4,029,000		25,527,000		3,240,000		5,500,000		2,922,000		10,000,000		47,112,000		10,000,000	
Number of reported incidents for each pollution source operation																																
Agricultural	79		74		51		84		131		114		88		87		77		117		108		132		113		161		145		118	
Industrial	103		169		209		199		193		244		195		139		177		199		213		231		189		196		168		122	
Municipal[3]	24		52		33		60		120		125		87		91		122		84		120		162		167		146		169		90	
Transportation	0		0		1		17		26		27		27		23		39		32		28		52		56		65		40		47	
Other	33		58		47		27		17		23		38		35		23		33		28		64		72		56		74		78	
Unknown	50		60		80		55		103		92		97		79		104		129		138		219		163		125		125		169	
Total reports	289		413		421		442		590		625		532		454		542		594		635		860		760		749		721		624	
Number of reports and fish killed by size grouping	No reports	No fish (millions)	No reports	No fish (millions)	No reports	No fish (millions)	No reports	No fish (millions)	No reports	No fish (millions)	No reports	No fish (millions)	No reports	No fish (millions)	No reports	No fish (millions)	No reports	No fish (millions)	No reports	No fish (millions)	No reports	No fish (millions)	No reports	No fish (millions)	No reports	No fish (millions)	No reports	No fish (millions)	No. reports	No. fish (millions)	No. reports	No. fish (millions)
1,000,000 or more	1	5.0	4	12.6	2	41.0	1	2.0	5	16.9	3	5.4	2	2.0	1	6.5	3	6.1	4	35.1	5	11.4	28	63.0	6	8.97	6	29.53	6	107.6	3	12.00
100,000 to 1,000,000	3	0.53	5	0.85	9	1.69	12	2.68	15	3.82	17	4.62	23	5.48	7	2.66	30	7.44	9	3.15	26	7.44	26	6.37	27	5.43	19	4.65	20	7.1	9	1.87
10,000 to 100,000	15	0.31	45	1.05	38	1.01	54	1.82	59	1.65	63	1.42	58	1.53	49	1.58	64	1.79	81	2.06	91	2.73	124	3.33	81	2.60	88	2.74	110	3.6	65	1.62
1,000 to 10,000	64	0.18	107	0.34	89	0.30	134	0.41	167	0.49	202	0.59	185	0.55	143	0.46	153	0.48	165	0.52	198	0.62	266	0.86	216	0.62	251	0.81	187	0.6	173	0.57
0 to 1,000	68	0.02	104	0.03	108	0.03	103	0.03	224	0.07	235	0.07	185	0.05	164	0.05	219	0.06	233	0.06	243	0.07	315	0.10	367	0.09	339	0.09	325	0.1	283	0.07
No size reported for incident	138		148		175		138		120		105		79		90		73		102		72		101		63		46		73		81	
Average duration of kill in days		2.95		2.64		2.59		3.18		2.44		2.57		2.71		3.34		2.99		3.11		3.25		3.35		3.40		2.72		3.50		2.18

[1] Derived after excluding reports of 100,000 kills or more as being unrepresentative

[2] Reporting system in effect for last six months of 1960

[3] Municipal operations include electric power-generating stations

* Source: U.S. Environmental Protection Agency, 1977a:4,5.

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TABLE B-3. EXTENT OF FISH KILL DAMAGE*

Item	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
RIVER											
Number of reports	189	240	259	271	339	292	251	219	264	356	487
Miles of stream	1,204	1,686	1,448	2,203	1,440	1,300	989	1,039	1,565	2,358	1,865
LAKES AND RESERVOIRS											
Number of reports	25	50	25	49	57	38	46	33	37	98	111
Acres affected	1,407	5,907	2,581	5,644	12,637	4,630	21,504	1,996	2,400	6,068	33,168

* Source: Dawson, Stradley, and Shuckrow, 1975, Vol.IV:92. (Data are only for reports where extent of damage was included.)

TABLE B-4. ANALYSIS OF 1970 FISH KILL DATA*

Source	Game fish killed	%	Non-game fish killed	%
Agricultural pesticides and fertilizers	264,391	7	1,149,472	10
Industrial	3,250,252	82	6,569,241	56
Transportation	284,782	7	3,616,348	31
Other	177,482	4	307,759	3
Total	3,976,907	100%	11,642,820	100%

* Source: Dawson, Stradley, and Shuckrow, 1975, Vol.IV:93.

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Threats from Land-based Disposal

Because waste disposal to land (both legitimate and covert) is a very diverse and common disposal approach, there are more data on the threats that can arise from this approach than from other techniques. EPA has collected and analyzed data on damage incidents that have arisen from land disposal of industrial wastes (Lazar, 1975/76; Lazar, 1975; Lazar, Testani, and Giles, 1976). Detailed descriptions of some of these incidents have also been published (Ghassemi, 1976; Shuster, 1976a, 1976b, 1976c; U.S. Environmental Protection Agency, 1977b; U.S. Environmental Protection Agency, 1975a, 1975b, 1976; Carter et al., 1975).

Lazar (1975/76) has found six major routes of environmental transport through which the land disposal (including lagooning, land application, landfilling, and dumping) of hazardous waste can result in damage, as follows:

1. Groundwater contamination via leachate;
2. Surface water contamination via runoff;
3. Air pollution via open burning, evaporation, sublimation and wind erosion;
4. Poisoning through direct contact;
5. Poisoning via the food chain;
6. Fire and explosion.

Table B-5 provides a matrix of transport mechanism versus disposal method for 421 damage cases arising from the land disposal of hazardous wastes. It will be noted that groundwater and surface water contamination are the two most prevalent transport mechanisms and that most incidents of direct contact poisoning arise from the category "other land disposal," i.e., "haphazard disposal on vacant properties, on farm land, spray irrigation, etc." (Lazar, Testani, and Giles, 1976). The mechanism of "poisoning through the food chain" is not represented in Table B-5, largely because of the difficulty of tracing some such incidents back to a specific source and also because one of the other identified transport mechanisms will normally be involved in the contamination of the lower order(s) in the food chain. However, some such incidents and potential incidents have been identified (Lazar, 1975/76).

Mechanisms of Water Contamination--

The mechanisms by which surface waters and groundwater can become contaminated from land disposal are of great interest in view of the frequency of such pollution events.

Surface waters--As noted earlier in this appendix, Dawson and co-workers have developed simple models for predicting the impact of spills that reach surface waters. In addition to spills from transportation and in-plant

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TABLE B-5. MECHANISMS INVOLVED IN DAMAGE INCIDENTS BY DISPOSAL METHOD[a]

Damage mechanism	Disposal method and number of cases				
	Surface Impoundments	Landfills, Dumps	Other land disposal[b]	Storage of wastes	Smeltings, slag, mine tailings
Number of cases	89 cases	99 cases	203 cases	15 cases	15 cases
Groundwater, 259 cases	57	64	117	10	11
Surface water, 170 cases	42	49	71	0	8
Air, 17 cases	3	5	9	0	0
Fires, explosions, 14 cases	0	11	3	0	0
Direct contact poisoning, 52 cases	1	6	40	5	0
Wells affected,[c] 140 cases	32	28	74	4	2

[a] Source: Lazar, Testani, and Giles, 1976:4. The data refer to 421 cases associated with land disposal of industrial wastes. The numbers in the matrix add up to more than 421 because several damage incidents involved more than one damage mechanism.

[b] Haphazard disposal on vacant properties, on farm land, spray irrigation, etc.

[c] Not included as a damage mechanism.

EPA-287 (Cin.)
(4-76)

accidents, surface waters can become contaminated by the overflowing of lagoons as a result of exceptional climatic conditions (e.g., flash floods, 100-year floods, etc.) and the failure of dams, etc., due to poor design or earthquake damage.

It is a feature of all surface water pollution mechanisms that the contamination occurs rapidly, and that in most cases, dilution and dispersion mechanisms limit the extent of the damage. This is borne out by the fish kill data presented in Tables B-2 and B-3, which show that the average kill duration is about three days, and that on the average, only a few miles of river are affected. Lakes which have comparatively small inflows and outflows constitute an exception to these remarks; the duration of polluting incidents may be long, as the dilution mechanisms are slow (Dawson and Stradley, 1975). Where pollutants reach estuaries, their physical behavior is complex, and their fate is highly variable (Dawson, Stradley, and Shuckrow, 1975, Vol.II).

Groundwater--Figure B-2 illustrates the processes by which groundwater can become contaminated. Percolation or leakage of leachates (including direct seepage of lagoon contents) into water-table (unconfined) aquifers constitutes the major threat. In contrast to surface water pollution, this process may take years or decades to become apparent. First, true leaching (of soluble and suspended materials derived from the solid portion of a waste) is a slow and often (depending on climatic conditions) intermittent process. Second, groundwater moves comparatively slowly; flow rates for most aquifers range from meters per day to meters per year (a few feet per day to a few feet per year [U.S. Environmental Protection Agency, 1977b]), and the average residence time of groundwater in an aquifer is of the order of 200 years (U.S. Environmental Protection Agency, 1977b).

These long time-constants are attested to both by theoretical (modeling) studies (Fenn, Hanley, and DeGeare, 1975; Konikow, 1977; Schultz, 1978; Elzy et al., 1974 [also see Elzy and Lindstrom, 1976]) and by numerous case studies of incidents involving leachates (U.S. Environmental Protection Agency, 1977b, 1976, 1975a, 1975b; Shuster, 1976a, 1976b, 1976c; Konikow, 1977; Walker, 1973). These studies also show that leachate contamination of groundwater is usually fairly restricted in its areal extent at any one time* but that the leachate frequently forms a plume or slug that travels in the direction of groundwater flow, often with little mixing. Naturally, individual details vary considerably, depending on the quantity and type of wastes involved, the climatic conditions at the disposal site, and the characteristics of the aquifer, including its ability to attenuate the waste by reacting with it.

---

* One of the larger recorded areas of contamination--approximately 3,000 hectares of severe pollution and 8,000 hectares over which traces of pollution could be detected--arose from discharge of several years of pesticide wastes to unlined evaporation ponds at the Rocky Mountain Arsenal, Colorado (U.S. Environmental Protection Agency, 1975b). The wastes contained a very high chloride concentration which enabled the extent of the contamination to be readily monitored (Konikow, 1977).

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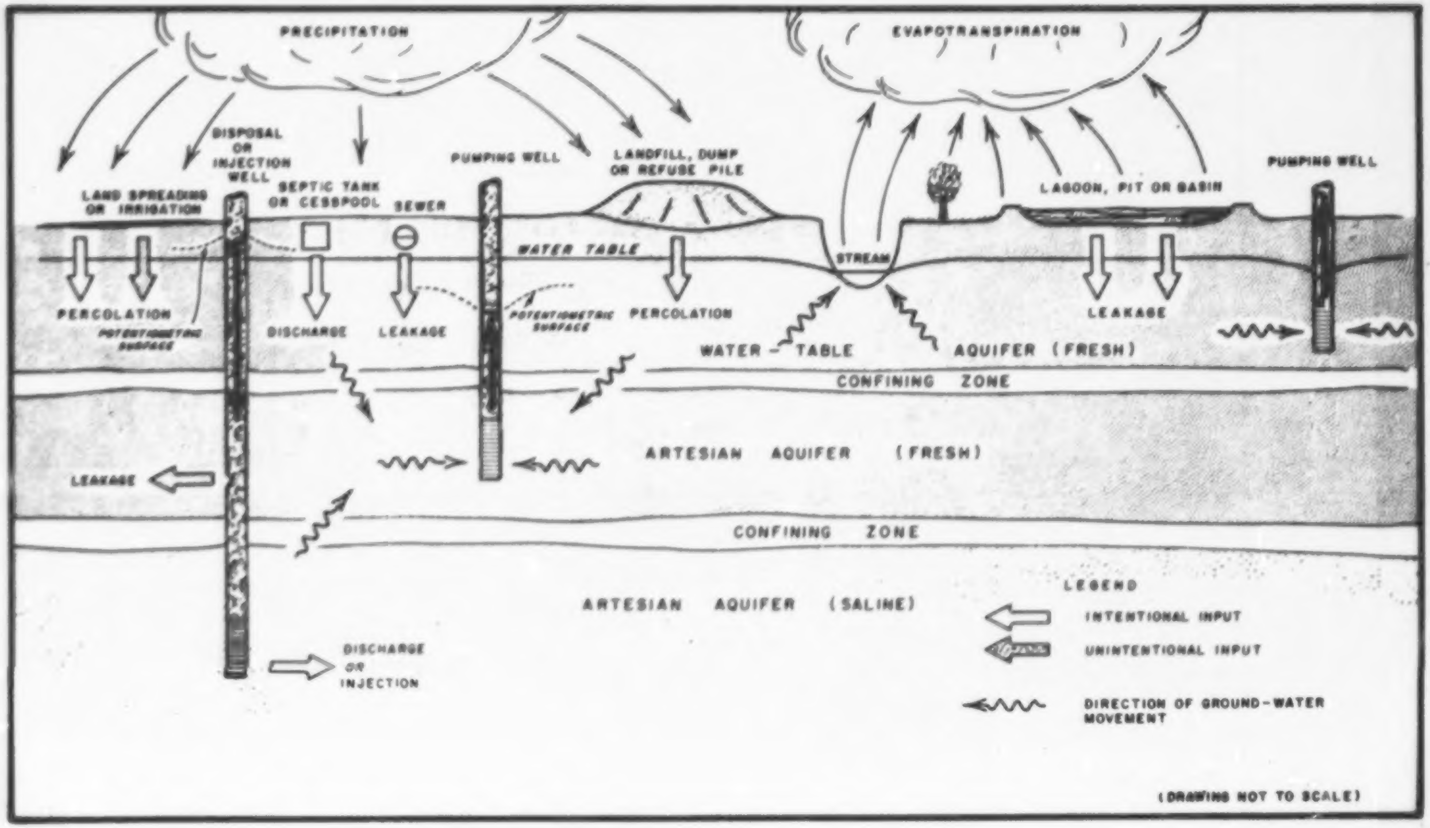
PRECIPITATION
EVAPOTRANSPIRATION
DISPOSAL OR INJECTION WELL
LAND SPREADING OR IRRIGATION
SEPTIC TANK OR CESSPOOL
SEWER
PUMPING WELL
LANDFILL, DUMP OR REFUSE PILE
STREAM
LAGOON, PIT OR BASIN
PUMPING WELL
WATER TABLE
PERCOLATION
POTENTIOMETRIC SURFACE
DISCHARGE
LEAKAGE
POTENTIOMETRIC SURFACE
PERCOLATION
LEAKAGE
WATER - TABLE AQUIFER (FRESH)
CONFINING ZONE
ARTESIAN AQUIFER (FRESH)
LEAKAGE
CONFINING ZONE
ARTESIAN AQUIFER (SALINE)
DISCHARGE OR INJECTION
LEGEND
INTENTIONAL INPUT
UNINTENTIONAL INPUT
DIRECTION OF GROUND-WATER MOVEMENT
(DRAWING NOT TO SCALE)

Figure B-2. Contamination of groundwater by waste disposal practices.

Source: U.S. Environmental Protection Agency, 1977b:83.

Table B-6 provides detailed data on 60 cases of groundwater contamination from landfills and dumps in the northeastern United States. Note that the mean annual potential evapotranspiration in this area is less than mean annual precipitation (U.S. Environmental Protection Agency, 1977b), a condition that encourages leaching from landfills.

Deep well injection--The primary threat from deep well injection is the contamination of a usable aquifer; but contamination of other valuable resources and adverse chemical reactions are possible (Warner and Orcutt, 1973). In addition, there are two known instances where deep well injection has stimulated earthquakes (Raleigh, 1972).

There are several mechanisms by which aquifers could become contaminated:

1. Lateral travel of injected waste to a region of freshwater in the same aquifer;

2. Escape of waste into a freshwater aquifer through some failure of the injection well casing or through some nearby deep well that is not adequately cased or plugged;

3. Vertical escape of the waste from the injection zone through confining beds that are inadequate because of high primary permeability, solution channels, joints, faults, or induced fractures;

4. Indirect contamination whereby injection of the waste displaces saline water into a freshwater aquifer (Warner and Orcutt, 1973).

Note that deep well injection will inevitably cause some modification of the local groundwater system. If this technique is to be used, the management objective should be to insure that whatever modification takes place does not have unanticipated effects. Again, the question of maintaining options arises. Saline water (usually defined as water containing 1,000 mg/l or more of dissolved solids) has traditionally been regarded as a nuisance and is only used where no other source is available. However, as Nace (1973) has pointed out, advances in desalting technology are changing saline water into an extensive resource, and potential alternative uses should be considered before wastes are injected into a saline aquifer.

The behavior of wastes injected into deep saline aquifers has been modelled by many authors. Recent publications on this topic include a review by Reeder et al. (1977) and a model developed for the U.S. Geological Survey (INTERCOMP Research Development and Engineering, Inc., 1976).

Environmental Impacts from Ocean Dumping

Unlike the threat posed by a possible accident, it can be stated with certainty that ocean dumping will have some effect on the marine environment. There will inevitably be some local contamination because of the mixing of

EPA-287 (Cin.)
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TABLE B-6. SUMMARY OF DATA ON 42 MUNICIPAL AND 18 INDUSTRIAL LANDFILL CONTAMINATION CASES*

Findings	Type of landfill Municipal	 Industrial
Assessment of principal damage		
Contamination of aquifer only	9	8
Water supply well(s) affected	16	9
Contamination of surface water	17	1
Principal aquifer affected		
Unconsolidated deposits	33	11
Sedimentary rocks	7	3
Crystalline rocks	2	4
Type of pollutant observed		
General contamination	37	4
Toxic substances	5	14
Observed distance traveled by pollutant		
Less than 30 m (100 ft)	6	0
30 to 305 m (100 to 1,000 ft)	8	4
More than 305 m (1,000 ft)	11	2
Unknown or unreported	17	12
Maximum observed depth penetrated by pollutant		
Less than 9 m (30 ft)	11	3
9 to 30 m (30 to 100 ft)	11	3
More than 30 m (100 ft)	5	2
Unknown or unreported	15	10
Action taken regarding source of contamination		
Landfill abandoned	5	6
Landfill removed	1	2
Containment or treatment of leachate	10	2
No known action	26	8
Action taken regarding groundwater resource		
Water supply well(s) abandoned	4	5
Groundwater monitoring program established	12	2
No known action	26	11
Litigation		
Litigation involved	8	5
No known action taken	34	13

* Source: Miller, DeLuca, and Tessier, 1974.

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the waste and the surrounding seawater (although if the wastes are containerized, the most serious contamination may be delayed until corrosion has breached the containers); hence the critical question becomes: Will this effect be localized or dispersed, and what impact will it have on the marine ecosystem?

The dispersion and transport processes that determine the physical fate of a dumped waste are comparatively well understood, and given sufficient input data, they are in many situations capable of being modelled (Ocean Disposal Study Steering Committee, 1976). However, even if the immediate physical fate of the dumped material can be predicted, this is only the beginning of the waste's effect on the ecosystem. Complex chemical interactions can occur between the waste and the seawater (Ocean Disposal Study Steering Committee, 1976), and most authorities agree that our understanding of the processes that determine the biological impact is very limited.

In a very broad study on ocean pollution, the National Academy of Sciences recently stated that:

> The greatest uncertainty in assessing the impact of ocean pollutants is the scarcity of data on their chronic toxicity. . . .
>
> Even if good experimental data were available on sublethal toxic effects of individual chemicals on representative species, it would be difficult to deduce effects on marine ecosystems. (National Academy of Sciences, 1975:6,7)

Nor is definitive information likely to be forthcoming in the near future. Another National Academy of Sciences study specifically directed towards waste disposal in the marine environment stated that:

> Once the assimilative capacity of a site and the limits on the rate of input of wastes are known, limiting conditions on waste composition, waste treatment, and waste dispersion or containment can be derived and a variety of designs to meet those conditions can be proposed. The necessary information for this is not now available, nor is it likely to be available in the near future. (Ocean Disposal Study Steering Committee, 1976:30)

In the absence of a detailed understanding of the interaction of wastes and the marine ecosystem, a case-study approach could be used to provide a very general impression of the possible impacts. Though most of the ocean disposal studies cited in Appendix A include descriptions of some of the observed environmental impacts of ocean disposal, very few specific data have been collected. Smith and Brown summarize the results of nine case studies on industrial wastes (Smith and Brown, 1971), and the two National Academy of Sciences studies catalog environmental impacts that have been attributed to ocean disposal (Ocean Disposal Study Steering Committee, 1976) and the known effects of some chemicals on ocean life (National Academy of Sciences, 1975).

PROBABILITIES THAT THREATS WILL OCCUR

General Discussion

The previous section has described categories of threat scenarios that may arise in hazardous waste management. For transportation accidents and for spills into water, some data that relate to the probability of occurrence of such threats were included. However, the emphasis has been on identifying the character of the threat, and this step alone is of value in analyzing hazardous waste problems, as social behavior may be influenced by the nature of the threat without much reference to its probability. Nevertheless, it would be useful to know more about the probabilities that threats will occur, as these data would be an integral part of any complete cost-benefit or risk-benefit analysis.

The initiating event (see Figure 4 in the main text) is usually the key to determining the probability that a threat will occur, although the threat mechanisms determine the outcomes, and hence affect the probability of any specific outcome. Some initiating events, i.e., those associated with ocean dumping and deliberate discharge to sewer or waterway, are not probabilistic in nature, while others such as sabotage and the effects of inadequate design or poor practice are inappropriate for a probabilistic approach. On the other hand, geologic and climatic events are amenable to probabilistic analysis, as are various forms of accidents.

The probabilities of most geologic and climatic initiating events will be site-specific, and analysis of the more common climatic events is already a routine operation. For example, landfill sites in California are evaluated with respect to the 100-year flood level and the precipitation from a 10-year, 24-hour storm (California State Water Resources Control Board, 1976). Note that virtually every initiating event is capable of occurring at various magnitudes. Taken over a long time span, the larger or stronger events almost invariably occur less frequently than smaller or weaker ones (e.g., a 500-year flood level will be higher than a 100-year flood level, strong earthquakes are less frequent than weak ones). Hence some judgment will be necessary as to the critical magnitude of an initiating event, based on the simplifying assumption that initiating events that are smaller than the critical magnitude will not lead to any adverse outcome.

There has been some research on predicting the probabilities and outcomes of less likely initiating events. Much of this work has stemmed from analysis of the safety of various aspects of the nuclear fuel cycle (Rasmussen, 1975), and in particular from the disposal of high-level radioactive wastes (Schneider and Platt, 1974, Vol.1; Energy Research and Development Administration, 1977; Claiborne and Gera, 1974). While this work has generally attempted to follow through the possible consequences of various initiating events by means of event trees, it was largely concerned with the danger from radioactivity; so the data are not generally useful for nonradioactive hazardous wastes. Deonigi (1974) provides a useful summary (with the emphasis on safety aspects) of the general methodology that has been developed for evaluating radioactive waste management concepts, and a related article by Burkholder et al. (1976) concentrates on the fate of radioactive wastes that are leached from geologic storage (mine disposal).

The data on the probabilities of various uncommon events and their outcomes that have been collected for evaluating the safety of nuclear-related activities are available in two forms: (1) Estimates of the probabilities of initiating events of sufficient magnitude to cause waste release from a specified form of disposal (usually mine disposal) and sometimes at a specified location, and (2) trade-off relationships between the frequency of occurrence of these events and the damages caused (property damage dollars and human fatalities) for the entire United States. The second form, which is available for both natural and man-caused events (see Figures B-3, B-4, and B-5), cannot be used directly for assessing the probabilities of critical magnitude initiating events, but it is a useful way to assess the relative importance of different events.

Uncommon Natural Initiating Events

Many of the threats to the more secure techniques for hazardous waste disposal will be initiated by unlikely climatic and geologic events. Since the time scale of interest may extend to perpetual care, not only sudden initiating events (such as earthquakes), but also gradual ones (such as erosion) could be of potential interest. Other than meteorite impact, which is regarded as a random process (Claiborne and Gera, 1974), the probabilities of all natural initiating events will be site-dependent to a lesser or greater extent, varying either with the general location (e.g., for earthquake) or with the specific details of the site (e.g., for flood). Various events are discussed below.

Earthquake--Seismic activity varies considerably within the United States. Schneider and Platt (1974) use a threshold level of IX on the Modified Mercalli Intensity Scale, which would result in the following effects:

> Damage considerable in specially designed structures; well designed frame structures thrown out of plumb; great in substantial buildings with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (Coffman and von Hake, 1972:4-7; quoted in Schneider and Platt, 1974).

Schneider and Platt (1974) calculate that the probability of an earthquake of at least this intensity striking a typical east coast site in the United States is about 2×10^{-5} per year, while for a random point in California, the probability would be some 2×10^{-2} per year. Clearly, better estimates of probability could be derived for specific sites. The risk from earthquakes would probably most affect storage structures, treatment facilities, and lagoons. The impact on wastes in the solid phase (in landfills or mines) would probably occur via changed water levels and paths.

Faulting and cracking--Faulting is considered to be the most likely aspect of tectonic activity (other than earthquake) that could interfere with waste disposal (Schneider and Platt, 1974). Faulting or cracking would most likely affect water paths and would be of particular importance for deep well injection, as it might cause saline aquifers to become connected to freshwater aquifers. Fault activities vary considerably within the United States,

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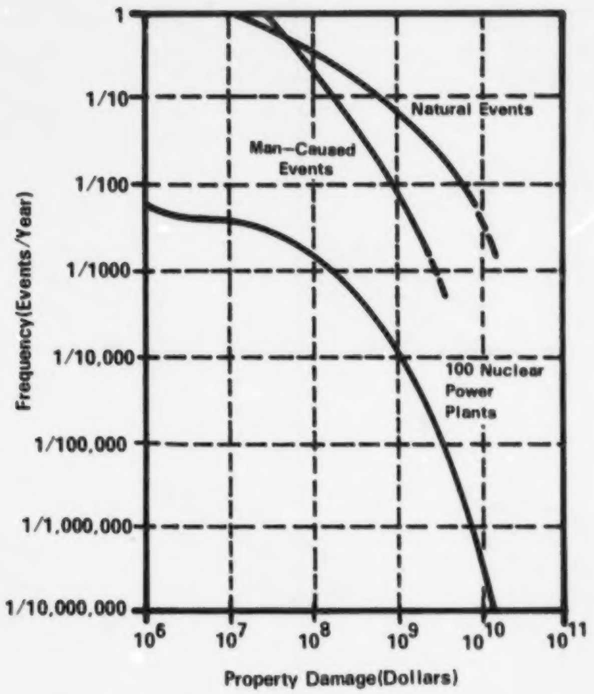

Notes:

1. Property damage due to auto accidents is not included because data are not available for low probability events. Auto accidents cause about $15 billion damage each year.

2. Approximate uncertainties for nuclear events are estimated to be represented by factors of 1/5 and 2 on consequence magnitudes and by factors of 1/5 and 5 on probabilities.

3. For natural and man caused occurrences the uncertainty in probability of largest recorded consequence magnitude is estimated to be represented by factors of 1/20 and 5. Smaller magnitudes have less uncertainty.

Figure B-3. Frequency of property damage resulting from natural and man-caused events.

Source: Rasmussen, 1975:A3.

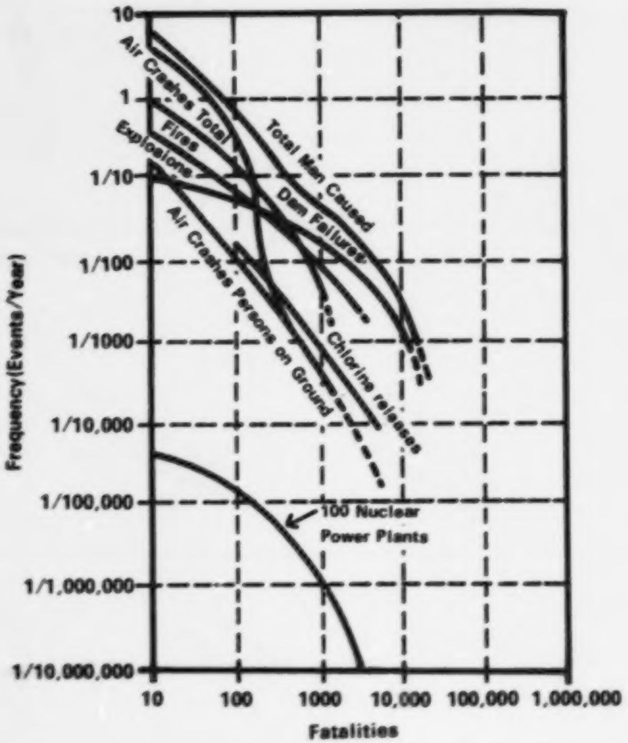

Figure B-4. Frequency of fatalities due to man-caused events.

Note: Fatalities due to auto accidents are not shown because data are not available. Auto accidents cause about 50,000 fatalities per year.

Source: Rasmussen, 1975:A2.

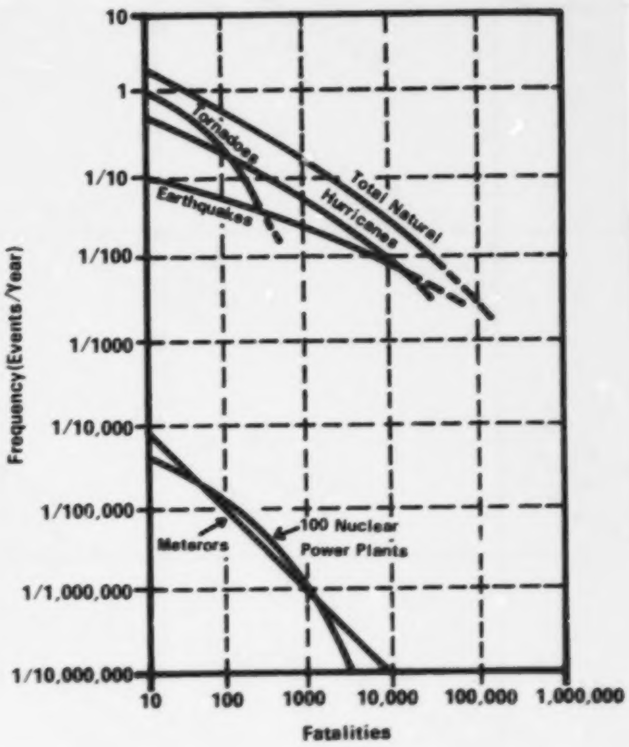

Figure B-5. Frequency of fatalities due to natural events.

Source: Rasmussen, 1975:A2.

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but as an example, one estimate places the probability that a new fault will intersect an 8 km^2 waste depository in the Delaware Basin, New Mexico, as $4x10^{11}$ per year (Claiborne and Gera, 1974). On the other hand, a study relating to Aiken, South Carolina, states that there is insufficient knowledge of the mechanisms to estimate the probability that a small crack will traverse a stratum (Energy Research and Development Administration, 1977).

Volcanic activity--Several authors consider that the probability of volcanic activity (in an area not currently active) is extremely low, but none care to estimate that probability (Schneider and Platt, 1974; Energy Research and Development Administration, 1977; Claiborne and Gera, 1974).

Erosion--The average rate of erosion for the entire United States is a few centimeters per thousand years, while maximum rates are of the order of meters per thousand years (Claiborne and Gera, 1974). However, as Schneider and Platt point out, in the arid and semiarid areas of the United States, river channel erosion can occasionally be rapid (e.g., of the order of a meter per decade), and cliffs (e.g., at the edges of mesas) can also retreat rapidly (Schneider and Platt, 1974). In arid areas, the flash floods associated with cloudbursts do not occur in well defined channels and can transport large quantities of material, possibly causing changes in drainage patterns (Schneider and Platt, 1974).

Erosion could primarily affect the long-term security of landfills, and the potential impact of flash floods and landslides on lagoons should also be considered when analyzing the siting of any land disposal facilities. The possibilities of glacial action and changes in sea level or the development of a lake have also been considered for the perpetual care of radioactive wastes (Schneider and Platt, 1974).

Development of an aquifer--Schneider and Platt (1974) include an interesting tentative estimate of the probability that an aquifer will develop where none currently exists, and that water will penetrate a mine disposal site (also see Deonigi, 1974). These data are presented in Table B-7. The probability that the water will penetrate the disposal tunnel and cavity is based on tunneling and natural gas storage experiences (Schneider and Platt, 1974). The development of an aquifer could affect all forms of land disposal.

Hurricanes and tornadoes--The strong winds associated with hurricanes and tornadoes would primarily affect surface structures (e.g., engineered storage) and could transport the contents of lagoons. Structure design to withstand the forces of high velocity winds is a normal engineering procedure.

The potential for damage from tornadoes has been evaluated with respect to nuclear power plants (see Rasmussen, 1975). The average incidence of a tornado at a nuclear power plant site has been calculated to be $5x10^{4}$ per year, but only 1 percent of these tornadoes are expected to exceed the design criteria (Rasmussen, 1975).

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(4-76)

TABLE B-7. SAMPLE COMPONENTS OF RELEASE SEQUENCE PROBABILITIES FOR GEOLOGIC DISPOSAL*

	Probability of waste release		
Failure event	During operational period	During 1,000 years	During 1,000,000 years
Aquifer develops in the region where one did not exist previously	10^{-10} to 10^{-8}	10^{-6} to 10^{-4}	10^{-2} to 10^{-1}
Water finds path into disposal site	10^{-4} to 10^{-2}	10^{-4} to 10^{-2}	10^{-4} to 10^{-2}
Water flow cannot be controlled by man	1	1	1
Water is flowing	1	1	1
Cumulative release probability in the time given	10^{-14} to 10^{-10}	10^{-10} to 10^{-6}	10^{-6} to 10^{-3}

* Source: Schneider and Platt, 1974:1.17.

Meteorite impact--The probability of the impact of large meteorites is low. Claiborne and Gera indicate that the probability of a meteor of mass in excess of 2×10^7 kg striking the earth is about 10^{-13} per km^2 per year. A meteorite of the above size would make a crater of about 1 km in diameter and 300 m deep (Claiborne and Gera, 1974). Schneider and Platt (1974) quote data suggesting that the probability of a meteorite being capable of forming a crater more than 400 m deep is 10^{-21} per km^2 per year. Such craters could threaten any form of land disposal. Smaller meteorites are more common, and the probability of a meteorite in the 10-tonne range striking a large surface building has been estimated to be less than 10^{-10} per year. Even so, this appears to be an event that can be neglected in comparison with many other uncontrollable risks.

Uncommon Man-caused Initiating Events

Aircraft impacts--The effects of an aircraft crash (including possible fuel combustion) have been investigated for nuclear power plants and waste processing facilities and for the transport of nuclear materials (Rasmussen, 1975; Energy Research and Development Administration, 1977). The risk from aircraft during surface transport is very small compared to other types of

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transport accidents, but due to the large quantities of energy that might be involved, this risk is of interest for materials (such as high-level radioactive materials) that are containerized securely enough to resist spillage in most accidents. The probability of a potentially damaging air crash at a reactor location in the United States that is more than five miles from any airport has been estimated to be 10^{-6} to 10^{-8} per year (Rasmussen, 1975).

Sabotage--Several authors have attempted to estimate the probability that facilities containing radioactive wastes will be sabotaged (Energy Research and Development Administration, 1977; Schneider and Platt, 1974; Claiborne and Gera, 1974). They conclude that the probability is low because there are more attractive targets for saboteurs. On the other hand, the security taken at any facility where sabotage could lead to disastrous consequences will reflect the attractiveness of the target, which will tend to even out the probabilities between different targets. Nevertheless, most techniques for the ultimate disposal of hazardous wastes would not appear to be particularly vulnerable to sabotage, but treatment facilities and engineered storage could be. Given a reasonable level of security at hazardous waste management facilities, it is difficult to predict the probability of a successful sabotage attempt without knowing more about the local political climate and alternative targets at the time.

REFERENCES

Angell, G.R., and A.S. Kalelkar. "The Cost of Relative Spill Hazards Associated With the Modal Transport of Hazardous Materials." In: *Control of Hazardous Material Spills. Proceedings of the 1974 National Conference on Control of Hazardous Material Spills*, Anon. ed. American Institute of Chemical Engineers and the U.S. Environmental Protection Agency, San Francisco, California, August 25-28, 1974. pp. 90-98.

Anon. ed. *Control of Hazardous Material Spills. Proceedings of the 1974 National Conference on Control of Hazardous Material Spills*. American Institute of Chemical Engineers and the U.S. Environmental Protection Agency, San Francisco, California, August 25-28, 1974. 387 pp.

Arthur D. Little, Inc. *Alternatives to the Management of Hazardous Wastes at National Disposal Sites*. Volume II. EPA/530/SW-46c-2, U.S. Environmental Protection Agency, Washington, D.C., 1973. [NTIS: PB237264]

Arthur D. Little, Inc. *A Modal Economic and Safety Analysis of the Transportation of Hazardous Substances in Bulk*. COM7411058, U.S. Department of Commerce, Maritime Administration, 1974.

Arthur D. Little, Inc. *Safety Considerations in Siting Housing Projects*. Contract No. H-2178R Modification 1, Department of Housing and Urban Development, Office of Policy Development and Research, Washington, D.C., 1975. 124 pp. [NTIS: PB253786]

Battelle Memorial Institute, Pacific Northwest Laboratories. *Program for the Management of Hazardous Wastes*. Volume I. EPA-530/SW54c-1, U.S. Environmental Protection Agency, Washington, D.C., 1974. 403 pp. [NTIS: PB233630]

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Booz, Allen, and Hamilton. *An Appraisal of the Problem of the Handling, Transportation, and Disposal of Toxic and Other Hazardous Materials.* Contract No. 05-00033, Environmental Quality Council, Washington, D.C., 1970. 180 pp. [NTIS: PB236599]

Buckley, J.L., and S.A. Wiener. *Hazardous Material Spills: A Documentation and Analysis of Historical Data.* EPA-600/2-78-066, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1978.

Burkholder, H.C., M.O. Cloninger, D.A. Baker, and G. Jansen. "Incentives for Partitioning High-Level Waste." *Nuclear Technology*, 31(November): 202-217, 1976.

California State Water Resources Control Board. *Waste Discharge Requirements for Nonsewerable Waste Disposal to Land: Disposal Site Design and Operation Information.* California State Water Resources Control Board, Sacramento, California, 1976. 60 pp.

Carter, C.D., R.D. Kimbrough, J.A. Liddle, R.E. Cline, M.M. Zack, Jr., W.F. Barthel, R.E. Koehler, and P.E. Phillips. "Tetrachlorodibenzodioxin: An Accidental Poisoning Episode in Horse Arenas." *Science*, 188(4189): 738-740, 1975.

Claiborne, H.C., and F. Gera. *Potential Containment Failure Mechanisms and Their Consequences at a Radioactive Waste Repository in Bedded Salt in New Mexico.* ORNL-TM-4639, Oak Ridge National Laboratories, Oak Ridge, Tennessee, 1974.

Coffman, J.L., and C.A. von Hake. *United States Earthquakes.* U.S. Department of Commerce, National Oceanic and Atmospheric Administration, Silver Spring, Maryland, 1972.

Dawson, G.W., and M.W. Stradley. "A Methodology for Quantifying the Environmental Risks From Spills of Hazardous Material." A paper presented at the AIChE Conference, Boston, Massachusetts, September 8, 1975. 35 pp.

Dawson, G.W., A.J. Shuckrow, and W.H. Swift. *Control of Spillage of Hazardous Polluting Substances.* 15090FOZ 10/70, Federal Water Quality Administration, Department of the Interior, Washington, D.C., 1970.

Dawson, G.W., M.W. Stradley, and A.J. Shuckrow. *Determination of Harmful Quantities and Rates of Penalty for Hazardous Substances. Volumes II, III, IV.* EPA-440/9-75-005, U.S. Environmental Protection Agency, Washington, D.C., 1975.

Deonigi, D.E. "Evaluation Methodology of Waste Management Concepts." *Nuclear Technology*, 24(3):331-338, 1974.

Elzy, E., and F.T. Lindstrom. "Model of the Movement of Hazardous Waste Chemicals for Sanitary Landfill Sites." In: *Proceedings of the Conference on Environmental Modeling and Simulation*, W.R. Ott, ed. EPA-600/9-76-016, U.S. Environmental Protection Agency, Washington, D.C., 1976. pp. 609-613.

EPA-287 (Cin.)
(4-76)

Elzy, E., F.T. Lindstrom, L. Boersma, R. Sweet, and P. Wicks. "Model of the Movement of Hazardous Waste Chemicals In and From a Landfill Site." In: Disposal of Environmentally Hazardous Wastes, Oregon State University Environmental Health Sciences Center Task Force on Environmentally Hazardous Wastes, Corvallis, Oregon, 1974. pp. 111-201.

Energy Research and Development Administration. Alternatives for Long-Term Management of Defense High-level Radioactive Waste, Savannah River Plant, Aiken, South Carolina. Volume 1. ERDA, 77-42/1, Energy Research and Development Administration, Washington, D.C., 1977.

Fenn, D.G., K.J. Hanley, and T.V. DeGeare. Use of the Water Balance Method for Predicting Leachate Generation from Solid Waste Disposal Sites. EPA/530/SW-168, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1975. 40 pp.

Ghassemi, M. Analysis of a Land Disposal Damage Incident Involving Hazardous Waste Materials, Dover Township, New Jersey. Contract No. 68-01-2956, U.S. Environmental Protection Agency, Washington, D.C., 1976. 127 pp.

INTERCOMP Resource Development and Engineering, Inc. A Model for Calculating Effects of Liquid Waste Disposal in Deep Saline Aquifers, Part I--Development. Water-Resources Investigations 76-61, U.S. Geological Survey, Reston, Virginia, 1976.

Jones, G.P., et al. Risk Analysis in Hazardous Materials Transportation. Volume I. Contract No. DOT OS 20114, Department of Transportation, 1973. 297 pp.

Kalelkar, A.S., L.J. Partridge, and R.E. Brooks, Jr. "Decision Analysis in Hazardous Material Transportation." In: Control of Hazardous Material Spills. Proceedings of the 1974 National Conference on Control of Hazardous Material Spills. Anon. ed. American Institute of Chemical Engineers and the U.S. Environmental Protection Agency, San Francisco, California, August 25-28, 1974. pp. 336-344.

Konikow, L.F. Modeling Chloride Movement in the Alluvial Aquifer at the Rocky Mountain Arsenal, Colorado. Water-Supply Paper 2044, U.S. Geological Survey, Washington, D.C., 1977. 48 pp.

Lazar, E.C. "Damage Incidents From Improper Land Disposal." Journal of Hazardous Materials, 1:157-164, 1975/76.

Lazar, E.C. "Summary of Damage Incidents From Improper Land Disposal." A paper presented at the National Conference on Management and Disposal of Residues from the Treatment of Industrial Wastewaters, Washington, D.C., 1975. 16 pp.

Lazar, E.C., R. Testani, and A.B. Giles. "The Potential for National Health and Environmental Damages from Industrial Residue Disposal." A paper presented at the National Conference on Disposal of Residues on Land, St. Louis, Missouri, September 15, 1976. 21 pp.

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Miller, D.W., F.A. DeLuca, and T.L. Tessier. *Ground Water Contamination in the Northeast States*. EPA 660/2-74-056, U.S. Environmental Protection Agency, Washington, D.C., 1974.

Munn, A. "Health Hazards to Workers from Industrial Chemicals." *Chemical Society (London) Reviews*, 4(1):82-89, 1975.

Nace, R.L. "Problems of Underground Storage of Wastes." *Journal of Research of U.S. Geological Survey*, 1(6):719-723, 1973.

National Academy of Sciences. *Assessing Potential Ocean Pollutants*. National Academy of Sciences, Washington, D.C., 1975. 458 pp.

National Academy of Sciences, Committee on Hazardous Materials, *Analysis of Risk in the Water Transportation of Hazardous Materials*. DOT-CG-41680-A, U.S. Coast Guard, Washington, D.C., 1976. 118 pp.

Ocean Disposal Study Steering Committee. *Disposal in the Marine Environment: An Oceanographic Assessment*. National Academy of Sciences, Washington, D.C., 1976. 85 pp.

Ott, W.R., ed. *Proceedings of the EPA Conference on Environmental Modeling and Simulation*. EPA 600/9-76-016, U.S. Environmental Protection Agency, Washington, D.C., 1976. 861 pp.

Rasmussen, N.C., director. *Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants*. WASH-1400, U.S. Nuclear Regulatory Commission, 1975. 207 pp. [NTIS: PB248201]

Raleigh, C.B. "Earthquakes and Fluid Injection." In: *Underground Waste Management and Environmental Implications*, T.D. Cook, ed., Memoir 18, The American Association of Petroleum Geologists, Tulsa, Oklahoma, 1972. pp. 273-279.

Reeder, L.R., J.H. Cobbs, J.W. Field, Jr., W.D. Finley, S.C. Vokurka, and B.N. Rolfe. *Review and Assessment of Deep-Well Injection of Hazardous Waste*. Volume I. EPA 600/2-77-019a, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1977. 215 pp.

Schneider, K.J., and A.M. Platt, eds. *High-Level Radioactive Waste Management Alternatives*. 4 volumes. BNWL-1900, Battelle N.W. Laboratories, Richland, Washington, 1974.

Schultz, D.W., ed. *Land Disposal of Hazardous Wastes: Proceedings of the Fourth Annual Research Symposium*. EPA-600/9-78-016, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1978.

Shuster, K.A. *Leachate Damage Assessment: Case Study of the Fox Valley Solid Waste Disposal Site in Aurora, Illinois*. EPA/530/SW-514, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1976a. 41 pp.

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Shuster, K.A. *Leachate Damage Assessment: Case Study of the Peoples Avenue Solid Waste Disposal Site in Rockford, Illinois*. EPA/530/SW/517, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1976b. 33 pp.

Shuster, K.A. *Leachate Damage Assessment: Case Study of the Sayville Solid Waste Disposal Site in Islip (Long Island), New York*. EPA/530/SW-509, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1976c. 25 pp.

Smith, D.D., and R.P. Brown. *Ocean Disposal of Barge-Delivered Liquid and Solid Wastes from U.S. Coastal Cities*. SW-19c, U.S. Environmental Protection Agency, Washington, D.C., 1971. 128 pp.

U.S. Department of Labor, Bureau of Labor Statistics. *Occupational Injuries and Illness in the United States by Industry, 1974*. Bulletin 1932, U.S. Department of Labor, Washington, D.C., 1976. 147 pp.

U.S. Environmental Protection Agency. *Report to Congress: Disposal of Hazardous Wastes*. SW-115, U.S. Environmental Protection Agency, Washington, D.C., 1974. 120 pp.

U.S. Environmental Protection Agency. *Hazardous Waste Disposal Damage Reports*. EPA/530/SW-151, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1975a. 12 pp.

U.S. Environmental Protection Agency. *Hazardous Waste Disposal Damage Reports*. Document No. 2. EPA/530/SW-151.2, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1975b. 16 pp.

U.S. Environmental Protection Agency. *Hazardous Waste Disposal Damage Reports*. Document No. 3. EPA/530/SW-151.3, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1976. 17 pp.

U.S. Environmental Protection Agency. *Fish Kills Caused by Pollution in 1975: Sixteenth Report*. EPA-440/9-77-004, U.S. Environmental Protection Agency, Washington, D.C., 1977a. 88 pp.

U.S. Environmental Protection Agency. *The Report to Congress: Waste Disposal Practices and Their Effects on Ground Water*. EPA-570/9-77-001, U.S. Environmental Protection Agency, Washington, D.C., 1977b. 531 pp.

Venugopal, B., and T.D. Luckey. "Toxicology of Non-Radioactive Heavy Metals and Their Salts." In: *Heavy Metal Toxicity, Safety and Hormology*. T.D. Luckey, B. Venugopal, and D. Hutcheson, eds. Academic Press, New York, New York, 1975. pp. 4-73.

Walker, W.H. "Where Have All the Toxic Chemicals Gone?" *Ground Water*, 11(2):11-20, 197[illegible].

Warner, D.L., and D.H. Orcutt. "Industrial Wastewater-Injection Wells in the United States--Status of Use and Regulation, 1973." *Proceedings: Second International Symposium on Underground Waste Management and Artificial Recharge*. Volume 2., J. Braunstein, ed. The George Banta Company, Inc., Menasha, Wisconsin, 1973. pp. 687-697.

APPENDIX C

VALUATION OF THE EFFECTS OF HAZARDOUS WASTE MANAGEMENT TECHNIQUES

This appendix discusses the nature of control costs and indicates how some of the common environmental impacts can be valued.

CONTROL COSTS

Generator's Costs

Generator's costs include all costs that the generator of a waste incurs specifically in dealing with its waste disposal problem. Generator's costs are the only costs that are internal to a firm, and therefore, according to classical microeconomic theory, they are the only costs that a firm is assumed to consider in its decisionmaking.

Generator's costs include any costs incurred by the generating firm to reduce the generation of hazardous waste, as well as those involved in waste separation, treatment, and disposal. They should include legal costs and taxes directly applicable to the waste handling and disposal operations (e.g., property taxes on relevant facilities or equipment), but not those that cannot readily be attributed to waste handling or disposal (e.g., income taxes). If the waste is subjected to any form of resource recovery, a credit for the value of the materials recovered (based on the cost of an alternative supply of that quality of material in that location) should be included, even if no market transaction is involved. Where a waste is consigned to another firm for treatment, transport, and/or disposal, the charges for these services are part of the generator's costs.

Generator's costs are comparatively easy to determine for a given waste and location. Hazardous waste management costs have been determined for various industries and for various methods of treatment and disposal. However, many of these data are highly location-specific or waste-stream-specific and are scattered throughout the literature. A few have been collated. For example, Battelle Memorial Institute, Pacific Northwest Laboratories (1974, Vol.II) provides costs for some widely applicable treatment modules; and Talley and Albrecht (1974) provide a comparison of costs for some disposal techniques, (Table C-1). An EPA-sponsored study to update and collate cost data for a wide range of hazardous waste treatment and disposal techniques has just been completed (U.S. Environmental Protection Agency, in progress).

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TABLE C-1. ESTIMATED COSTS OF SOME DISPOSAL TECHNIQUES*

Technique	Estimated costs		
	Range	Average	"Normalized"
LAND BURIAL TECHNIQUES			
Conventional sanitary landfill	$1.98-$4.74/tonne	$3.30/tonne	$0.99/m^3
Near-surface land burial containerized wastes		$26.50/m^3	$26.50/m^3
Sludge encapsulation and burial			
Operating experience of one company	$7.80-$31.80/m^3		$7.80-$31.80/m^3
Polymer encapsulation		$26.40/m^3	$27.20/m^3
Cement encapsulation		$66.10/m^3	$66.00/m^3
Asphalt		$35.20/tonne	$42.40/m^3
Deep burial	$11.30-$33.90/m^3		$11.30-$33.90/m^3
ENGINEERED STORAGE	$106-$177/m^3		$106-$177/m^3
DEEP WELL INJECTION	$0.13-$0.53/m^3		$0.13-$0.53/m^3
OCEAN DISPOSAL			
Bulk	$0.66-$10.50/tonne	$1.87/tonne	$1.87/m^3
Containerized	$5.50-$143.00/tonne	$26.40/tonne	$26.40/m^3

* Source: Talley and Albrecht, 1974. (Data were converted from U.S. customary units.)

EPA-287 (Cin.)
(4-76)

A major problem that may be encountered in attempting to determine generator's costs for planning purposes is the variability of such costs with local conditions, even if the level of environmental protection is not concurrently varied. Although disposal costs (for a given technique) are not, in general, sensitive to the precise composition of the wastes involved, treatment costs can vary considerably. For example, Arthur D. Little, Inc. (1973, Vol.I) showed a variation in total operating costs from 0.3 to 15.6 cents per liter (1973 data) for treatment of various wastes containing heavy metals. (These wastes were dilute heavy metals, concentrated heavy metals, and organics with heavy metals. Data excluded sludge disposal costs and were for waste stream volumes typical of large-sized industrial plants.) Furthermore, major economies for scale are possible. Arthur D. Little, Inc. (1973, Vols.I and II) assumed an exponent of -0.4 in the average unit processing cost/throughput relationship for all treatment processes considered. (The term "processing cost" appears to refer to labor and capital related costs only, and to exclude chemicals and utilities which were taken as constant unit costs.)

Disposal costs will, however, depend on geologic and climatic factors, such as the depth and injection pressure needed for deep well injection, the suitability of the location for evaporation ponds, and the relative ease with which secure (chemical) landfills can be constructed. Talley and Albrecht's data (Table C-1) are based on a single source of data for each technique, and yet typically they show variations of 2:1 to 4:1, with a far larger range for ocean disposal. This varies "according to geographical area, type of waste, distance [from port] to the disposal area and annual volume of wastes handled" (Smith and Brown, 1971).

Administrative Costs

Administrative costs include the costs of planning, promulgating regulations, monitoring compliance, and prosecuting noncompliance with regulations, studying incidents and problems, and advising industry. These costs will be incurred by various levels of government and by watchdog bodies that are concerned with environmental quality. Research and development costs should not be included unless they are integrally associated with a particular approach to hazardous waste control.

It is often difficult to derive precise data on the administrative costs involved in a particular program area, because of multiple coverage by many government departments. For example, a legal department or a laboratory will probably handle the work of many program areas and will not be restricted to hazardous wastes. Fortunately, the analyst is primarily interested in changes in administrative costs as the approaches to hazardous waste control are varied, and these can more readily be estimated by assessing the cost of employing the additional staff directly needed to implement programs, together with an allowance for support from service departments, consultants, etc.

Few empirical data have been published on administrative costs, and those that have are generally broad in coverage. For example, 1977 Federal

EPA-287 (Cin.)
(4-76)

expenditures for standard setting and enforcement in relation to all pollution control activities were estimated to be $422 million (Council on Environmental Quality, 1976). However, it is widely held that administrative costs can vary substantially with different regulatory approaches. The National Academy of Sciences (1975) highlighted this variability, and suggested that the magnitude of regulatory administrative costs should be considered in selecting an appropriate regulatory action. Also, in assessing the potential efficacy of alternative institutional approaches to the management of hazardous wastes, Battelle Memorial Institute, Pacific Northwest Laboratories (1974, Vol.I) gave Federal cost a weighting of one-seventh in deriving an effectiveness ranking. Administrative costs can be expected to increase as the extent of regulation is increased (as opposed to achieving objectives by use of market forces) and as the degree of environmental protection or quality is increased.

Although crude, an approach that is sometimes adopted is to take administrative costs as a fixed proportion of some other major cost. For example, Moll et al. (1977) suggested that administrative and enforcement costs incurred by governments for pollution control activities might amount to 10 percent of the annualized costs of the relevant industrial pollution controls.

Effluent fees or fines for the violation of standards may be used to internalize costs external to a firm and can thereby affect its behavior. However, because fines and effluent charges are only transfer payments between different categories of control costs, any contribution that they make to overall economic efficiency must be by means of changes in pollution control activities. In work oriented toward the control of fly ash emissions from power plants, Downing and Watson have analyzed the effect of an agency's enforcement activities on a firm's projected behavior under the assumption of cost minimization (Downing and Watson, 1974, 1977; Watson and Downing, 1976). They compared the effects of effluent fees with standards and fines, and they examined the effects of using different compliance tests and numbers of inspections, as well as different levels of fines and effluent fees. One conclusion was that for the parameters involved in the fly ash control situation, a firm's optimum strategy would involve frequent violation of standards (Watson and Downing, 1976). In recent work, Downing and Kimball (no date) examined the pollution control behavior adopted by firms in a number of industries and found that the firms appear to be controlling pollution to a greater degree than would be implied by a cost minimization strategy. Although Downing and Kimball examined a number of possible explanations, they were unable to satisfactorily explain the observed behavior.

Social Control Costs

The category of "social control costs" is introduced to catch hidden or intentional subsidies provided to enterprises that have to dispose of hazardous waste. For example, to encourage adequate disposal of wastes, governments might elect to provide landfill services at no cost, or at a cost below that which would be justified on an economic basis. This would constitute an intentional subsidy that should be taken into account when comparing the total costs of alternative disposal techniques. A more subtle

EPA-287 (Cin.)
(4-76)

subsidy--and one that may not be restricted to services provided by governments--can occur where the opportunity cost or the replacement cost of a facility (such as a landfill) is higher than the historic cost or accounting cost. For example, even in the absence of inflation, an accounting cost could readily understate the capital component of landfill costs. Often, the land employed was obtained at low cost; but with the growth of the community that it serves, both the opportunity cost reflecting the value of the land in alternative uses, and the cost of replacing the facility with another that is functionally equivalent would be far higher than the historic cost. Government charters may preclude landfill operation in such a way as to make a book profit, and individual firms often base their charges on historic costs, not recognizing the need to consider opportunity costs or to plan for facility replacement.

Social control costs--both deliberate and unintentional--can arise with most hazardous waste management techniques. Highway users, for example, may not pay the full cost of providing and maintaining the highway system. Where this type of cost exists, it is important that its presence is recognized and that it is included in the evaluation if it is a significant factor. In cost-benefit analysis, a "shadow price" is sometimes used to reflect the true cost of a transaction, as opposed to the actual money cost, if any. This is equivalent to adding the social control cost to the generator's cost.

Social control costs are external to the waste generator, who will therefore not take them into account in his decisionmaking. However, such costs might deliberately be incurred for some techniques to steer generators' decisions toward ones that are efficient from a societal viewpoint (i.e., when all costs and damages are considered).

VALUATION OF ENVIRONMENTAL IMPACTS

This section discusses the valuation of environmental impacts that may arise from hazardous wastes. Some economic theory that may be used in such valuations is presented followed by discussion on the valuation of commonly encountered categories of impact. These categories have been organized largely on the basis of the valuation techniques that might be used, and a given waste management technique may result in impacts in more than one category.

Theoretical Considerations

Willingness-to-Pay--

The valuation of environmental impacts is frequently more difficult than the valuation of control costs, as there are no established markets for many effects (e.g., a change in water quality). Although some authorities consider that monetary values should not be assigned to certain effects (Tihansky, 1975), in principle it is almost invariably possible to impute a value from some sort of willingness-to-pay survey or equivalent measure. This involves asking affected consumers how much they would be willing to pay to receive a specified benefit, even though it might be impossible or unfeasible to collect such payments. Because it is often difficult to develop a willingness-to-pay survey that is not subject to bias, willingness-to-pay is frequently imputed from some observed behavior.

EPA-287 (Cin.)
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The term "willingness-to-pay" is frequently used to encompass two separate concepts that can lead to quite different results under certain circumstances. Thus there is a distinction between an individual's willingness-to-pay to obtain increased utility, and the compensation that an individual would demand to accept a reduction in utility (Freeman, 1978). (The term "willingness-to-pay" is commonly employed to encompass either measure, except where the distinction is important.) If an individual's marginal utility of income is approximately constant (as where the changes are very small compared to total income) the two measures can be taken as equivalent (Freeman, 1978). However, in some circumstances, the distinction can be important, as willingness-to-pay is limited by an individual's income, whereas compensation demands are not. Consequently some individuals may indicate that they would not accept certain situations at any level of compensation (Prato, 1974). Thus the compensation that an individual would require to accept a reduction in his life expectancy or to undertake an activity that carries a given chance of death could be far greater than the payment that he would be prepared or able to make to increase his life expectancy by a similar amount, or to avoid an activity that has the same chance of death (Hirshleifer, Bergstrom and Rappaport, 1974).

The measurement of willingness-to-pay for environmental improvement is difficult, as individuals can have strong incentives for concealing their true preferences (Mäler and Wyzga, 1976). Thus in responding to a questionnaire or in a bidding game, it is in the interest of those responding to overstate their willingness-to-pay if their responses carry no financial obligations. If the amount they will actually pay is essentially independent of their responses, they are likely to promote the perceived improvement in the quality of the environment to the maximum extent possible by exaggerating their responses. On the other hand, if there is a direct individual financial obligation associated with the responses, it is in the interest of an individual to understate his response in the hope that other persons will bear the brunt of improvement costs. (This is an example of the "free-rider" problem that can arise with public goods.) In the context of valuation of amenity benefits, Mäler and Wyzga (1976) suggest ways in which it may be possible to obtain a balance between these two opposing effects by making an individual partly financially responsible for his statements. However, it appears that it has not yet been found feasible to apply this technique to the estimation of environmental benefits, so the questionnaire approach is likely to result in a biased valuation.

The Consumers' Surplus--

In valuing some environmental effects it is necessary to determine the consumers' surplus, or more commonly to evaluate a change in the consumers' surplus. This is of particular importance where no market (or an imperfect market) exists for the product. For example, the total value of a recreation opportunity is often evaluated by determining the consumers' surplus, which (if income effects are neglected) is the triangular area on a demand curve above the price actually paid. This area represents the total that consumers would be prepared to pay to receive that benefit (e.g., recreational opportunities in a park) above any price that they actually pay (e.g., an entry fee). A discriminating monopolist would be able to capture the entire consumers' surplus by charging each individual exactly what he was prepared

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to pay for the benefit. If pollution reduces the attractiveness of recreational opportunities in the park, then the demand curve will be lower, and the cost of that pollution (as far as its effect on the park is concerned) will be the reduction in the consumers' surplus.

Where the distinction between willingness-to-pay to obtain a product or service and the compensation required to forego it is significant, there are two different measures of the consumers' surplus. The *compensating variation* measures the consumers' surplus in the former case, and the *equivalent variation* measures it for opportunities foregone. For a normal (as opposed to inferior) good, the compensating variation is smaller than the area under the demand curve, which in turn is smaller than the equivalent variation. However, where income effects are negligible, the three measures coincide. In practice, although goods having zero income effect are uncommon, the effect is often sufficiently small for the area under the demand curve to be used with acceptable accuracy in many cost-benefit analyses (Mishan, 1971a).

Unfortunately, analysis of environmental problems is complicated by the fact that consumers can be highly emotional about giving up their rights, with the result that the two measures are *not* equivalent. This situation was, for example, found to pertain to waterfowl hunting (Brown and Hammack, 1972) and to the public's stated views about changes in air quality in the Four Corners area where Arizona, Colorado, New Mexico and Utah meet (Randall, Ives, and Eastman, cited in Prato, 1974). Because of the difficulty of designing survey instruments that elucidate genuine responses to willingness-to-pay questions (and especially those that relate to compensation required), there may be considerable uncertainty about the true magnitude of a consumers' surplus.

Destruction and Damage to Manmade Property

Destruction and damage to manmade property can be a comparatively easy category of environmental damage to value. If some replacement of the damaged item is required, then replacement cost will provide a suitable method of valuation where the replacement is *functionally equivalent* to the damaged item. Though in many cases this can be assessed on the basis of the cost of a similar item (less an allowance for depreciation where appropriate), there will be situations where direct replacement is inappropriate. For example, where wells are irreversibly contaminated, the damage cost should include the cost of providing an alternate water supply. Provision of an alternate water supply from a different source is likely to be far more costly than drilling a direct replacement for the original well.

On the other hand, there could be circumstances in which the appropriate replacement cost was less than that of replacing the damaged item with a direct equivalent. Due to changing technology, the direct replacement of some structures (e.g., a fire-damaged barn) with a physically identical structure could be more costly than replacement with a functionally equivalent structure of different design. Of course, replacement of damaged property with something that is functionally equivalent but physically different could also cause a social impact by changing the aesthetic value associated with the property.

In other cases, because of changing demand or technology, replacement would be inappropriate, as there might be some better means of utilizing the resources or solving the problem. For example, if an abandoned mine that was being used for hazardous waste disposal were destroyed by an explosion, it would be inappropriate to calculate the cost of replacing the mine, since some completely different disposal technique would probably be adopted. However, in this case, a "value in use" could be attributed to the mine, probably based on the costs of an alternative waste disposal technique.

Damage to Human Life and Health

Loss of Human Life--

The valuation of human life has recently been discussed by Hirshleifer, Bergstrom, and Rappaport (1974), Zeckhauser (1975), and Linnerooth (1976, 1975a,b). Linnerooth (1976) identifies six approaches, as follows:

1. The human-capital approach: Each life is valued according to the discounted future earnings of the beneficiary;
2. The insurance approach: Each life is valued on the basis of individual life insurance decisions;
3. The court-decided compensation approach: Here information from court awards for fatal accidents or diseases is used to value each life;
4. The implicit-value approach: Each life is valued according to values implicit in past decisions affecting human mortality;
5. The portfolio approach: Changes in mortality risk are compared with the entire portfolio of risks assumed by society;
6. The utility, or willingness-to-pay approach: This approach values risk reduction by the public's preferences or willingness to pay for this reduction.

The human-capital approach is probably the best known and widely used, although it has been criticized on the grounds that it values livelihood and not lives (Linnerooth, 1976). Within this approach, there is an important subdivision between the gross value version, which evaluates an individual's lifetime earnings, and the net value version, which only considers the economic loss that would be suffered by others should that individual die, (i.e., it excludes his consumption or maintenance cost) (Linnerooth, 1975b). Despite this significant philosophical distinction (as an individual's consumption is likely to be a large portion of his earnings), values derived by both versions of the approach have clustered around $200,000 (in 1958 to 1974 dollars) (Linnerooth, 1975b).

The next three approaches (2, 3, and 4) have not received as much attention as that of the human-capital approach and can lead to a wide range of results. For example, life valuations derived from the implicit-value approach have ranged from $9,000 to $9 million (Linnerooth, 1976). On the other hand, there is evidence that court-decided compensation is related to the human-capital approach, as court awards for loss of life are frequently based on the expected future earnings of the deceased.

A major difficulty associated with all of the first four approaches is that they can lead to the conclusion that for some sectors of society, lives have no value. These sectors are non-wageworkers (e.g., homemakers and retired persons) and persons with no dependents (for the insurance approach). Although there are ways to circumvent this problem, it does point up the inadequacy of these approaches.

The last two approaches (5 and 6) are of particular interest for risk-benefit analyses as they express mortality risk in probabilistic terms, as opposed to dealing with *ex ante* identifiable persons. Thus they are considered appropriate to decisions where life expectancy or the probability of death is altered (Linnerooth, 1976, 1975b), as is the case with hazardous waste management decisions.

By far the most widely known example of the portfolio approach is the work of Starr (1969, 1972), who drew the important distinction between risks undertaken voluntarily and those that are involuntary. This approach has been criticized by several authors (Slovic, Fischhoff, and Lichtenstein, 1976; Linnerooth, 1975b; Mishan, 1971b), essentially on the grounds that the sociopolitical decisionmaking process reflected in these data does not reveal the true public preference for risk-benefit trade-offs. (This topic is discussed in more detail in Appendix F.)

The willingness-to-pay approach is advocated by some authors as the only conceptually valid way of valuing life--i.e., by basing the valuations on utility (Mishan, 1971b; Schelling, 1968). The approach is potentially capable of recognizing nonlinearities in the risk-benefit trade-off relationship, but it is fraught with difficulties in use.* There have been a few questionnaire-type surveys (see Linnerooth, 1975b), and Thaler and Rosen (1973) have attempted to use the "risk premium" associated with the remuneration for hazardous jobs to obtain a value of life. Once again, both survey and risk premium results suggest a value of life in the region of $200,000 (based on *small* increases in mortality).

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* For example, an individual might accept a 0.1 percent decrease in survival probability to receive $200. If this applied to many individuals, it would lead to an *ex post* life valuation of $200,000. However, the same individual might require a million dollars to accept a 50 percent reduction in survival probability (leading to an *ex post* life valuation of $2 million), and he would probably be unwilling to accept any compensation--however great--in exchange for certain death. Thus in this example the *ex ante* risk-benefit trade-off relationship is nonlinear (see Hirshleifer, Bergstrom, and Rappaport, 1974).

Damage to Human Health--

The valuation of sickness and accidents appears to have received less attention than loss of life. Most valuations appear to be based on the human-capital approach, plus an allowance for medical expenses. This approach is, of course, implicit in Workman's Compensation and other insurance schemes, and such data could be used as a measure of work-related damages to life and health.

Values of lost workdays derived from the human-capital approach do not include an allowance for pain and suffering. This factor (together with allowances for medical expenses) is often present in court-awarded injury compensation. In some empirical studies, an allowance for pain and suffering has been included as a proportion of the other costs of accidents and illness (e.g., 25 percent of monetary costs [Garwood and Newby, cited by Tihansky, 1976]), but in most studies no explicit allowance has been made.

The National Academy of Sciences (1977) recently used $50 per working day as the lost income that would result from a disability. They argued that the nonworking population was included indirectly in their calculations by means of resource transfers. Unfortunately, this study did not estimate the associated reduction in medical costs that would result from reduced disabilities, nor did it make an allowance for pain and suffering. Several other authors have also used the $50 per lost workday figure (e.g., Brewer, 1976; Hub et al., 1973). However, Hub et al. (1973) restrict the valuation of accidents to those that are "external" to the risky situation to avoid double counting (i.e, they assume that the labor cost for a worker exposed to health risks reflects at least some of the costs of these risks). This is the same concept as the wage risk premium mentioned above.

The distinction between internal and external risk-bearers is important. It implies that if the risk premium correctly reflects the additional risks undertaken, it is unnecessary to evaluate the risk to life and limb of workers normally involved with hazardous waste management activities, and only involuntary risks to bystanders need be considered. Thus part of the wages paid to an operator at a hazardous waste disposal facility should, in theory, reflect the higher level of job-related risk over that of a similar job dealing with nonhazardous materials. While the risk premium may be reasonably accurate in an occupation like underground coal mining where there is a history of accidents and illness (e.g., black lung disease) known to the workers (see Otway and Cohen, 1975), it is less likely to reflect accurately the risk in a hazardous waste management facility, because the risks will in most cases be poorly defined.

Involuntary risks to bystanders' lives and health can arise in many ways from hazardous waste management activities. For example, the risk incurred by individuals along waste transport routes are involuntary, as are those that arise from undetected contamination of water supplies or foodstuffs due to waste leaching or overflow.

EPA-287 (Cin.)
(4-76)

Damage or Destruction to Animals, Vegetation and Land Ecosystems

Commercial Crops and Livestock--

Commercial crops could be damaged or destroyed by overflow from lagoons or treatment facilities, and could be affected by airborne pollution from nearby hazardous waste facilities. Land application could affect subsequent crops on the same site, while animals could eat or drink contaminated materials.

It is probably reasonable to assume that agricultural products face a market of pure competition. In this event, destruction of commercial crops and stock animals can readily be valued at market prices, although savings that arise from not needing to harvest and market the crop or products could be subtracted if significant. Cleanup costs should be included where necessary, and adequate allowance should be made for long-lived effects, such as reduced crop yield or the need to plant less valuable crops in future years.

Valuation of Wildlife, Etc.--

Although damage to land-based ecosystems from hazardous waste spills and severe air pollution is likely to be quite localized, the damage potential to aquatic systems is probably one of the more important environmental impacts that can arise from hazardous wastes (see Appendix B). Methods of valuing wildlife and associated ecosystems, both land and aquatic, largely amount to the valuation of recreation opportunities in natural surroundings. Recreation might include hunting, fishing, camping, hiking, boating, etc. In addition, there may be an "option value" associated with the preservation of natural environments, which will be discussed later.

Ashton, Wykstra, and Nobe (1974) discuss six recognized approaches to the valuation of non-market supplied recreational opportunities. Although some of these approaches are seriously flawed, they are included here because the reader may find them in use and should therefore be able to recognize them and understand their limitations. They are as follows:

1. The expenditure method: Measures the value of recreation in terms of the total direct private expenditures on recreation;

2. The gross-national-product method: An attempt to measure the contribution of recreation to GNP;

3. The consumers'-surplus method: Determines the willingness of individuals to pay for various quantities of recreation;

4. The cost method: Uses the cost of supplying recreational facilities as a measure of the benefits derived therefrom;

5. The market-value method: Is based on fees charged at private resorts as a proxy for the value of public-supplied facilities;

6. The monopoly-revenue method: Relies on the estimated revenue that would be obtained by a nondiscriminating monopolist owning a recreation site as a measure of the benefits.

The most important approaches are the expenditures method and the consumers'-surplus method. The expenditure method is simple to apply and is widely used; Ashton, Wykstra, and Nobe (1974) cite a variety of studies that have resulted in valuations of \$3.89 to \$28 per recreation day (in 1952 to 1966 dollars). One approach to the consumers'-surplus method is to ask consumers what they are willing to pay for the recreational opportunities. While attractive theoretically, as already indicated, this approach is fraught with practical difficulties. Alternatively, in both the consumers'-surplus and monopoly-revenue methods, travel distances, and hence differential travel costs can be used to impute a value (or rent) for recreational opportunities.

The cost method is conceptually unsound and is rarely used nowadays; but its successor, the market-value method, is difficult to apply in practice. The appropriate version of the gross-national-product method involves tracing the contributions to regional or national income that arise from the recreational activities of interest. Thus this method includes secondary effects and would be inconsistent with other valuations used in this study. Note, however, that each method discussed here is not merely a different way of arriving at the same result, but it is in fact a different measure of the value of recreation. Fortunately, the consumer-surplus and monopoly-revenue methods generally give results that are similar in magnitude to those obtained by the expenditure method (see Ashton, Wykstra and Nobe, 1974), so that the significant philosophical differences need not cause too many problems in practice.

Other useful discussions on the valuation of recreation may be found in Clawson (1972), Clawson and Knetsch (1966), Krutilla and Fisher (1975), Krutilla (1972), Edwards et al. (1976), and Pearse (1968). Most work has concentrated on the valuation of a recreation-day, as this is most readily measured. However, in many situations it may be desirable to be able to value individual species (this is particularly useful for fish as it permits fish kill data to be used). For game animals (known as "consumptive" or "harvested" species), it is common to deduce an average animal value from the number of hunter-days (often estimated from license data), the average expenditure or some other measure of the value of a hunter-day, and the number of animals harvested (Ashton, Wykstra, and Nobe, 1974). Valuations yielded by this procedure have been used within a cost-benefit analysis framework to determine the cost of destroying areas of wildlife habitat, based on the number of animals that the habitat would support (Norman et al., no date).

Unfortunately, the average animal-value approach has some serious drawbacks. First, for the purpose of evaluating any specific wildlife kill, a marginal value should ideally be used. Second, it values animals as though they were harvested and does not take account of the need to propagate the species for future years. Finally, it cannot be applied to nonharvested species.

There have been some attempts to overcome these difficulties. Brown and Hammack (1972) have developed a questionnaire-based methodology (applied to migratory waterfowl) to derive a marginal value for game animals that recognizes the variability of hunting success and the effort of constraints such as the bag limit. Inevitably, a major difficulty associated with determination of marginal rather than average values is the more complex data requirements; this is probably why most analysts use average values.

The need to propagate the species is usually taken into account by valuing breeding areas or young in terms of the yield to harvestable adults and the value of these adults. For example, Brown and Hammack (1972) derive a valuation for nesting areas based on survival probabilities and hunting yields, while the Oregon Department of Fish and Wildlife (1977) has developed similar methods for valuing spawning gravel and brood fish in anadromous fisheries. This approach does not take account of changed competition for food, or the effects of reduced populations on hunting activities and yields; but to attempt to do so would indeed be a profound undertaking.

Valuation of nonharvested wildlife presents greater difficulties. Though similar methodologies to those used for arriving at the value of a hunter-day can be used to determine the value of a recreation-day, the valuation of specific species is very difficult. As far as the author is aware, nonharvestable species valuation has only been attempted once (Norman et al., no date) and in this case, the values were derived by reviewing the harvestable values and making subjective comparisons. Thus in this case, the value of a harvested black bear was established at $6,400; the value of a grizzly bear (which is not harvested) was subjectively set at $20,000 on the basis of comparison with the black bear. (Telephone interview, R.L. Norman, Colorado Division of Wildlife, Grand Junction, Colorado, November 21, 1977.)

Fish and Other Aquatic Life Kills in Surface Waters

Damage to Noncommercial Fishing, Etc.--

The considerations that apply to the valuation of noncommercial fishing and to water-related recreation have already been discussed under the valuation of wildlife, etc.

Damage to Commercial Fishing--

While land-based crop and animal losses can reasonably be valued at market prices, valuation of lost commercial fishing is more difficult, as in this case, resources are primarily expended in harvesting the fish (as opposed to raising the crops or animals) and therefore, it would be possible to arrive at a zero valuation for reduced fishing yield, if the resources could be employed in alternative uses that were equally productive. In practice, the resources are likely to be immobile, except in the very long run,* and Brown et al. (1976) concluded that the benefits of increased yields

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* Gordon (1972) argues that the operation of a typical competitive fishery is such as to yield no net economic rent, and that some fishing grounds may be exploited at a level of negative marginal productivity. He states that fisherman are one of the least mobile of occupational groups and they will work for less than the "going wage." Bromley (1969) confirms the low mobility of resources and argues that some of the unique features of the commercial fishing industry justify the observed labor immobility on grounds of social efficiency. Much additional information on the economics of fisheries may be found in Peterson and Fisher's (1977) survey of the economics of extractive resources.

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could be valued at market prices to the fishermen plus an increase in the consumers' surplus. The change in the consumers' surplus arose because the demand for fish (salmonids in this case) was assumed to be local, and an increased catch would cause a decrease in price.

Similar arguments could be applied to decreases in yield due to hazardous waste incidents, but unless the incident was such as to have a substantial effect on the local catch, the decrease in the consumers' surplus could be neglected. If the physical effects were permanent, the loss to society could probably be restricted to several years or at the most to one generation, as fishing resources would not be immobile forever.

The Impacts of Ocean Dumping--

Valuation of the environmental impacts of ocean dumping is made difficult by the diversity of possible effects (see Appendix B). It may, however, be useful to identify and value the activities that are at risk from ocean dumping. These include commercial and sport fishing, ocean recreation opportunities (skin diving, swimming, etc.), and general tourism. The valuation of fishing and recreation has already been discussed; tourism is most commonly valued in terms of its commercial impact by using tourists' expenditures as a base. Because tourists' expenditures are usually assumed to be exogenous to the area, secondary (multiplier) effects are commonly included. In general, this study disregards such effects, but the local impact of multiplier effects probably should be noted when lost tourism is considered.

Some estimates of economic damages from actual hazardous materials and oil spills are available. For example, cleanup costs for oil spills have ranged from $0.13 to $4 per liter (Enk, 1974). However, available estimates have rarely, if ever, attempted to evaluate all costs.

Changes in Property Values

The concept that pollution will affect land values and that land or property values can thereby be used as some measure of the public's perception of pollution has received much attention from environmental economists. Unfortunately, analysis of empirical data is far from simple and has met with only limited success (Fisher and Peterson, 1976). Most attention has been paid to the impact of air pollution on property values, it being argued that property value differentials provide an indication of individual willingness-to-pay to reduce pollution. The theoretical underpinning and the practical problems associated with the use of land rents or property values as a measure of external effects are described by Schmalensee et al. (1975). However, there remains some debate as to exactly what can be inferred about pollution from property value data (see Polinsky and Shavell, 1975).

The results of several empirical studies of air pollution on property values are discussed by Waddell (1974). An indication of the magnitude of the effect is provided by Waddell's conclusion that an increase of 0.1 mg $SO_3/100\ cm^2$ per day (which would represent a doubling of the background rate for sulfation in the U.S.) would decrease residential property values by $100 to $600.

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Tihansky (1975) cites some studies that attempted to relate property values to water pollution. Unfortunately none of these studies provided clear-cut results that could be helpful in evaluating hazardous waste management problems.

Schmalensee et al. (1975) endeavored to assess the impact of sanitary landfills on residential property values. In a study of values of residential property adjacent to four sanitary landfills in Los Angeles County, they found a general lack of significant detrimental environmental effects. In one case truck noise associated with the fill had a negative effect on property values, but both proximity and view of the fill had positive effects, presumably because of the anticipated transformation of the fill to a recreational site. Note, however, that these results related to well operated sanitary landfills, where air and water pollution were not problems.

Except perhaps where there is severe air pollution, it appears that changes in property values are quite local. For sanitary landfills, the effects do not appear to extend beyond one or two miles (see Schmalensee et al., 1975). Thus this aspect of the adverse impacts of hazardous waste management techniques can be minimized by locating any site well away from residential and other susceptible properties. As landfills used for the disposal of hazardous waste are unlikely to be converted to recreational sites, increases in property values would not be anticipated.

Though property values may reflect actual physical pollution, they may also reflect psychological influences. The fear that property values may be reduced is frequently encountered when landfill sites are being considered, and local citizens will often oppose the establishment of a landfill for this reason (U.S. Environmental Protection Agency, 1976). Despite the safeguards used in a well operated chemical landfill or other waste management facility, the situation may be exacerbated when it comes to hazardous waste operations, reflecting a greater degree of perceived threat. The author is aware of two instances in which industrial waste disposal sites were closed as a result of public pressure. While incidents of this type are complex, it does appear that concern about property values was involved in both cases.*

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* The Antioch, California, landfill and lagooning facility operated by a subsidiary of Industrial Tank Company was closed as a result of public pressure after a housing subdivision was built adjacent to it. The residents of the subdivision complained of air pollution but continued to press for closure after the lagoons had been filled in and capped. The same company operates two other treatment and disposal sites in the San Francisco Bay area, but after strongly contested public hearings, the firm was unable to secure a land use permit for a proposed site near Brentwood, California. (Personal interview, C.G. Schwarzer, California Department of Health, Berkeley, California, February 7, 1977.) To avoid a repetition of the Antioch situation, the company has obtained control of a buffer zone of several thousand acres (used for agricultural purposes) around its 280-acre

EPA-287 (Cin.)
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Changes in property values are of particular importance with respect to equity since changes that are caused by a hazardous waste activity can in part be regarded as transfer payments. (These transfer payments would be between those whose property values had fallen and those whose property values had risen; and, to the extent that the price changes did not reflect changes, in utility between a seller and a buyer of a property.) In addition to these transfer payments, there is the overall external effect of the hazardous waste management activity on the welfare of the householders. An adverse impact will, in aggregate, reduce the utility of the properties to the householders, thereby decreasing welfare.

To summarize: One can be reasonably sure that some hazardous waste management techniques will--like many industrial activities--affect the value of adjacent properties. These changes in value are indicative of external effects associated with the hazardous waste management activities, but they only provide a true measure of the external effects under very limited circumstances (Schmalensee et al., 1975; also see Fisher and Peterson, 1976). In practice, changes in property values are largely important with respect to equity.

Aesthetic Factors and Option Values

This category of effects is included to cover individuals' values that do not normally enter the marketplace. The effects are highly indirect; an individual does not necessarily have to observe the environmental feature of interest to possess these values. They may conveniently be divided into aesthetic value, existence value, and two types of option value. There are no zero levels of aesthetic and existence values, so for these factors, costs must be expressed in terms of differences. Option values, however, do have zero levels, and hence it is possible to use absolute values if desired.

Aesthetics may enter into the valuation of most of the environmental effects already discussed--for example, property values and the willingness-to-pay for recreation opportunities partly reflect aesthetic considerations. However, there may be situations where only aesthetic values are involved, such as the attractiveness of a river with clear water as opposed to turbid water, and the discussion here is intended to cover those situations.

Benica, California, site. (Personal interview, F. Balisteri, Pacific Disposal Systems, Inc., Martinez, California, February 3, 1977.)

Another industrial waste disposal site near Pasco, Washington, operated by Resource Recovery Corporation was closed after the Franklin County Commissioners refused to renew its land use permit. The company has attempted to establish operations elsewhere in eastern Washington but has met with opposition to its proposals (Stradley, Dawson, and Cone, 1975). The Pasco site closure occurred after a newspaper had suggested that its handling of the herbicide 2,4-D could threaten local grape crops. However, it was later demonstrated that no such physical damage had occurred. (Personal interview, T. Cook et al., Washington Department of Ecology, Olympia, Washington, March 8, 1977.)

Since changes in these nonmarket values between different hazardous waste management schemes are difficult to measure, the analyst may in some cases simply wish to identify these costs rather than place a dollar value on them. However, there are techniques that can permit values to be assigned to these costs, and these are discussed below.

Aesthetic Value--

The aesthetic value of concern here is what might be termed "environmental aesthetics," as opposed to the aesthetics of art, design, city planning, etc. Thus it is the value that an individual places on the physical environment to reflect that individual's taste and desire for beauty, and for natural surroundings, etc.

No direct costs can be associated with most changes that offend or please a person's environmental aesthetic values. Virtually the only way of placing a dollar figure on this type of aesthetic value would be some measure of willingness-to-pay, derived either directly from questionnaires or bidding games, or indirectly from studies of human behavior such as the travel studies used to value recreation benefits.

Some authorities propose the use of a Delphi technique to estimate aesthetic damages (Kennedy et al., 1976; CONSAD Research Corporation, 1975; Mäler and Wyzga, 1976). Delphi techniques are widely used in technological forecasting and to some extent in technology assessment. The method involves the use of a panel of experts who, through a controlled interactive process, attempt to reach consensus in answering certain questions that usually involve prediction. For more details of the Delphi method, see Linstone and Turoff (1975). Though the Delphi method might have some promise for identifying different aesthetic considerations, the use of the opinions of a panel of experts as a surrogate for those of the public is questionable.

Existence Value--

In addition to the aesthetic value of the environment to an observer of that environment, there may be an existence value associated with the environment. This is the value that some persons place on knowing that something exists, even if they never expect to see it or benefit from it (Fisher and Peterson, 1976). This value is largely associated with major irreplaceable features of the environment (e.g., the Grand Canyon) and with rare or endangered species. Existence value can include the possible scientific benefits from preserving a species, an ecosystem or a natural feature, and also includes an aesthetic aspect that values diversity, etc.

A good example of existence value was provided by one of the comments on the Environmental Impact Statement for the prototype Federal oil shale leasing program. It appeared to come from an old man in Ohio, who evidently did not want some of the canyons in the vicinity of the oil shale formations destroyed by depositing spent shale in them. He said, "I have never seen a canyon, let alone those in Colorado, Wyoming, and Utah. . . . please do not destroy the beauty of what God put there . . . if it cost more to keep the land and animals I would rather spend the extra money" (Burris, 1973).

EPA-287 (Cin.)
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Another illustration of existence value was the drive to preserve the only known habitat of the snail darter on the Little Tennessee River, which halted a major dam project (Cook, Cook, and Grove, 1977). In this case, some individuals believed that the preservation of this species was worth more than the tens of millions of dollars irretrievably committed to the dam project. Note, however, that in this case, the costs of preserving the snail darter would not fall on those advocating preservation. This is akin to demanding compensation for an environmental change, whereas the first example illustrates genuine willingness-to-pay.

Determination of existence values again involves attempting to ascertain the individual's willingness-to-pay to preserve that existence, which is probably even more difficult to accomplish than determining aesthetic values. Nevertheless, confrontations such as the dispute over the snail darter illustrate the very high existence values that some people attribute to rare environmental features.

Option Values--

Option value refers to the benefits of keeping an option available. Like existence value, it is only relevant to irreversible actions that foreclose some future use of the feature of interest. The best known example is probably Krutilla's analysis of the benefits of maintaining Hell's Canyon (on the Oregon-Idaho border) in its natural state (Krutilla and Fisher, 1975). Key aspects of the analysis are that a decision to dam the Snake River in Hell's Canyon would be irreversible, and that in the future the value of the recreational benefits conferred by maintaining the river in its natural state is likely to increase, whereas technological advance (in alternative power sources) is likely to reduce the real value of hydroelectric power generated by the dam(s). Thus in this case, the implications of technical change are said to be "asymmetric" (because the supply of wilderness areas cannot be increased) (Krutilla, 1967), and maintaining a natural environment is expected to make an important contribution to man's future welfare.

There has been some debate as to exactly what option value represents and how it differs from the consumers' surplus. It is generally held that option value can take two forms: One (often called "option demand") that represents a risk aversion premium associated with uncertain future demand (and which is in addition to consumers' surplus), whereas the other reflects the benefit of not undertaking an irreversible project while society waits for improved information about the benefits of alternative uses of our resources (usually the environment) (Fisher and Peterson, 1976). It is this second form of option value that has potentially important implications for hazardous waste management. As Arrow and Fisher (1974) point out, where a pollutant is nondegradable (and may therefore have irreversible effects), any decision about its discharge to the environment should take into account the option value associated with delaying any action until more data about its effects and about alternatives are obtained. This option value must be balanced against any increased costs associated with the delay.

General--

While it is easy to postulate existence values and option demand, a pervasive difficulty with such nonuser effects is to determine the number of people who hold these values. These numbers can be very large--for example, the Alaska pipeline issue must have been known to a large proportion of the U.S. population, and hence even if only a small percentage of those people were concerned about the potential damage to the environment, the nonuser benefits of environmental preservation could have been substantial (see Bishop and Cicchetti, 1975).

Another aspect of aesthetic values, existence values, and option demand arising from risk aversion that should be mentioned is that values are likely to vary substantially among individuals. It is even possible to postulate changes that would provide a positive aesthetic benefit to some individuals and a negative one to others. Consider, for example, the choice between leaving land as a wilderness and farming it. Some people may prefer wilderness because they see farming as the introduction of a nonnatural ecological monoculture. Others may prefer to see the land farmed, associating farming with a satisfying, traditional way of life. While individuals may place differing valuations on market-traded goods (giving rise to the consumers' surplus), in most instances the variation is probably larger with nonmarket-traded goods, e.g., recreational oppportunities. If the results of willingness-to-pay surveys on improving the environment can be trusted, this variation can be very large (several orders of magnitude) for aesthetic and existence values. (See Appendix D.)

This variation in individuals' values raises some difficult questions for decisionmakers. These questions essentially revolve around equity. For example, to what extent is it reasonable to provide or deny very large benefits to a few individuals, when the benefits to most others are small? A similar problem arises where the individual's true willingness-to-pay (or to take avoiding action) is limited by a low discretionary income. If this low willingness-to-pay is accepted at its face value, we may be making the judgment that society should value the welfare of that person less than that of an affluent person. This type of implication should be considered when alternative policy approaches are evaluated.

REFERENCES

Arrow, K.J., and A.C. Fisher. "Environmental Preservation, Uncertainty, and Irreversibility." *Quarterly Journal of Economics*, 88(2):312-319, 1974.

Arthur D. Little, Inc. *Alternatives to the Management of Hazardous Wastes at National Disposal Sites*. 2 volumes. EPA/530/SW-46c, U.S. Environmental Protection Agency, Washington, D.C., 1973. [NTIS: PB225164, PB237264]

Ashton, P.M., R.A. Wykstra, and K.C. Nobe. *Optimum Supplies of Recreation Days Under Conditions of Uncertainty: A Case Study Application to Wildlife Resources*. Department of Economics, Colorado State University, Ft. Collins, Colorado, 1974. 98 pp.

Battelle Memorial Institute, Pacific Northwest Laboratories. *Program for the Management of Hazardous Wastes*. 2 volumes. EPA-530/SW-54c, U.S. Environmental Protection Agency, Washington, D.C., 1974. [NTIS: PB233630/1]

EPA-287 (Cin.)
(4-76)

Bishop, J., and C. Cicchetti. "Some Institutional and Conceptual Thoughts on the Measurement of Indirect and Intangible Benefits and Costs." In: Cost Benefit Analysis and Water Pollution Policy, H.M. Peskin and E.P. Seskin, eds. The Urban Institute, Washington, D.C., 1975. pp. 105-126.

Brewer, S.T. "Quantification and Comparison of External Cost of Nuclear and Fossil Electrical Power Systems." In: Energy and the Environment: Cost-Benefit Analysis, R.A. Karam, and K.Z. Morgan, eds. Pergamon Press, New York, New York, 1976. pp. 506-530.

Bromley, D.W. Economic Efficiency in Common Property Natural Resource Use: A Case Study of the Ocean Fishery. Working Paper No. 28, Bureau of Commercial Fisheries, Division of Economic Research, Oregon State University, Corvallis, Oregon, 1969. 174 pp.

Brown, G.M., Jr., and J. Hammack. "A Preliminary Investigation of the Economics of Migratory Waterfowl." In: Natural Environments: Studies in Theoretical and Applied Analysis, J.V. Krutilla, ed. The Johns Hopkins University Press, Baltimore, Maryland, 1972. pp. 171-204.

Brown, W.G., D.N. Larson, R.S. Johnson, and R.J. Wahle. Improved Economic Evaluation of Commercially and Sport-Caught Salmon and Steelhead of the Columbia River. Special Report 463, Agricultural Experiment Station, Oregon State University, Corvallis, Oregon, 1976. 33 pp.

Burris, T. "Letter No. 90." In: Final Environmental Statement for the Prototype Oil Shale Leasing Program. Volume V. U.S. Department of the Interior. U.S. Government Printing Office, Washington, D.C., 1973.

Clawson, M. "Methods of Measuring the Demand for and Value of Outdoor Recreation." Paper presented at a meeting of the Taylor-Hibbard Club, University of Wisconsin, January 13, 1959. Resources for the Future Reprint #10. Washington, D.C., 1972. 10 pp.

Clawson, M., and J.L. Knetsch. The Economics of Outdoor Recreation. The Johns Hopkins Press, Baltimore, Maryland, 1966. 348 pp.

CONSAD Research Corporation. Cost/Benefit Techniques for Hazardous Materials, Toxic Substances, Solid Waste Control. Contract No. 68-01-3116, U.S. Environmental Protection Agency, Washington, D.C., 1975. 383 pp.

Cook, S.G., C. Cook, and D. Grove. "What They Didn't Tell You About the Snail Darter and the Dam." National Parks and Conservation Magazine, 51(5):10-13, 1977.

Council on Environmental Quality. Environmental Quality - 1976: Seventh Annual Report. U.S. Government Printing Office, Washington, D.C., 1976. 398 pp.

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Downing, P.B., and J.N. Kimball. Enforcing Environmental Regulations. Working Paper No. CE-77-3-3, Department of Economics, Virginia Polytechnic Institute and State University, Blacksburg, Virginia, no date. 50 pp.

Downing, P.B., and W.D. Watson, Jr. "Economic Considerations in Enforcing Environmental Controls." Advances in Environmental Science and Technology. Volume 7. J.N. Pitts, Jr. and R.L. Metcalf, eds. John Wiley and Sons, Inc., New York, New York, 1977. pp. 423-514.

Downing, P.B., and W.D. Watson, Jr. "The Economics of Enforcing Air Pollution Controls." Journal of Environmental Economics and Management, 1:219-236, 1974.

Edwards, J.A., K.C. Gibbs, L.J. Guedry, and H.H. Stoevener. The Demand for Non-Unique Outdoor Recreational Services: Methodological Issues. Technical Bulletin #133, Agricultural Experiment Station, Oregon State University, Corvallis, Oregon, 1976. 60 pp.

Enk, G.A. "The Social Impacts of Hazardous Materials Spills." In: Control of Hazardous Materials Spills: Proceedings of the 1974 National Conference on Control of Hazardous Material Spills. American Institute of Chemical Engineers and the U.S. Environmental Protection Agency, San Francisco, California, August 25-28, 1974. pp. 143-148.

Fisher, A.C., and F.M. Peterson. "The Environment in Economics: A Survey." Journal of Economic Literature, 14(1):1-33, 1976.

Freeman, A.M., III. "Benefits of Pollution Control." In: Critical Review of Estimating Benefits of Air and Water Pollution Control, A. Hershaft, ed. EPA 600/5-78-014, U.S. Environmental Protection Agency, Washington, D.C., 1978.

Garwood, F., and R.F. Newby. "Use of Chi-squared Distribution for Comparing Accident Frequencies." In: Road Research, Proceedings of the Symposium on the Use of Statistical Methods in the Analysis of Road Accidents. Road Research Laboratory, Crowthorne, England, 1969.

Gordon, H.S. "The Economic Theory of a Common Property Resource: The Fishery." In: Economics of the Environment: Selected Readings, D. Dorfman, and N.S. Dorfman, eds. W.W. Norton and Company, Inc., New York, New York, 1972. pp. 88-99.

Hirshleifer, J., T. Bergstrom, and E. Rappaport. Applying Cost-Benefit Concepts to Projects Which Alter Human Mortality. UCLA-ENG-7478, School of Engineering and Applied Science, University of California, Los Angeles, California, 1974.

Hub, K.A., J.C. Asbury, W.A. Buehring, P.F. Gast, R.A. Schlenker, J.T. Weills, K.P. DuBois, and J.L. Gardner. Social Costs for Alternate Means of Electrical Power Generation for 1980 and 1990. 4 volumes. ANL-8093, Argonne National Laboratories, Illinois, 1973. 1050 pp.

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EPA-287 (Cin.)
(4-76)

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Kennedy, R., R. Lowrey, A. Bernstein, and F. Rueter. *A Benefit-Cost System for Chemical Pesticides*. EPA 540/9-76/001, U.S. Environmental Protection Agency, Washington, D.C., 1976. 322 pp. [NTIS: PB250988]

Krutilla, J.V. "Conservation Reconsidered." *American Economic Review*, 57(4):777-786, 1967.

Krutilla, J.V., ed. *Natural Environments: Studies in Theoretical and Applied Analysis*. The Johns Hopkins University Press, Baltimore, Maryland, 1972. 362 pp.

Krutilla, J.V., and A.C. Fisher. *The Economics of Natural Environments: Studies in the Valuation of Commodity and Amenity Resources*. The Johns Hopkins University Press, Baltimore, Maryland, 1975. 214 pp.

Linnerooth, J. *A Critique of Recent Modelling Efforts to Determine the Value of Human Life*. RM-75-67, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1975a. 51 pp.

Linnerooth, J. *The Evaluation of Life-Saving: A Survey*. RR-75-21, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1975b. 31 pp.

Linnerooth, J. "Methods for Evaluating Mortality Risk." *Futures*. 8(4):293-304, 1976.

Linstone, H.A., and M. Turoff, eds. *The Delphi Method: Techniques and Applications*. Addison-Wesley Publishing Co., Reading, Massachusetts, 1975.

Mäler, K.G., and R.E. Wyzga. *Economic Measurement of Environmental Damage; A Technical Handbook*. Organisation for Economic Cooperation and Development, Paris, France, 1976. 151 pp.

Mishan, E.J. *Cost-Benefit Analysis: An Introduction*. Praeger Publishers, New York, New York, 1971a. 374 pp.

Mishan, E.J. "Evaluation of Life and Limb: A Theoretical Approach." *Journal of Political Economy*, 19(4):687-705, 1971b.

Moll, K., S. Baum, E. Capener, F.W. Dresch, and R.M. Wright. *Hazardous Wastes: A Risk-Benefit Framework Applied to Cadmium and Asbestos*. EPA-600/5-77-002, U.S. Environmental Protection Agency, Washington, D.C., 1977. 268 pp. [NTIS: PB257951]

National Academy of Sciences. *Considerations of Health Benefit-Cost Analysis for Activities Involving Ionizing Radiation Exposure and Alternatives*. EPA 520/4-77-003, U.S. Environmental Protection Agency, 1977. 199 pp.

National Academy of Sciences. *Decision Making for Regulating Chemicals in the Environment*. National Academy of Sciences, Washington, D.C., 1975. 242 pp.

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Norman, R.L., L.A. Roper, P.D. Olson, and R.L. Evans. Using Wildlife Values in Benefit/Cost Analysis and Mitigation of Wildlife Losses. Colorado Division of Wildlife, Denver, Colorado, no date. 21 pp.

Oregon Department of Fish and Wildlife. "Economic Data Used by Fishery Biologists." In: Manual for Fish Management. Oregon Department of Fish and Wildlife, 1977. pp. 168-192.

Otway, H.J., and J.J. Cohen. Revealed Preferences: Comments on the Starr Benefit-Risk Relationships. RM-75-5, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1975. 17 pp.

Pearse, P.H. "A New Approach to the Evaluation of Non-Priced Recreational Resources." Land Economics, 44(1):87-99, 1968.

Peterson, F.M., and A.C. Fisher. "The Exploitation of Extractive Resources: A Survey." The Economic Journal, 87(348):681-721, 1977.

Polinsky, A.M., and S. Shavell. "The Air Pollution and Property Value Debate." The Review of Economics and Statistics, 57(1):100-104, 1975.

Prato, A.A. "Internalizing Environmental Externalities of Energy Resource Developments." In: Economics of Natural Resource Development in the West. Human Resources and Natural Resources Committees of the Western Agricultural Economics Research Council, 1974. pp. 51-67.

Randall, A., B.C. Ives, and C. Eastman. Benefits of Abating Aesthetic Environmental Damage from the Four Corners Power Plant. Agricultural Experiment Station Bulletin 618, New Mexico State University, Fruitland, New Mexico, 1974.

Schmalensee, R., R. Ramanathan, W. Ramm, and D. Smallwood. Measuring External Effects of Solid Waste Management. EPA-600/5-75-010, U.S. Environmental Protection Agency, Washington, D.C., 1975. 448 pp.

Schelling, T.C. "The Life You Save May Be Your Own." In: Problems in Public Expenditure Analysis, S.B. Chase, Jr., ed. The Brookings Institution, Washington, D.C., 1968. pp. 127-176.

Slovic, P., B. Fischhoff, and S. Lichtenstein. "Cognitive Processes and Societal Risk Taking." In: Cognition and Social Behavior, J.S.Carroll and J.W. Payne, eds. Lawrence Erlbaum Associates, Potomac, Maryland, 1976. pp. 165-184.

Smith, D.D., and R.P. Brown. Ocean Disposal of Barge-Delivered Liquid and Solid Wastes from U.S. Coastal Cities. SW-19c, U.S. Environmental Protection Agency, 1971. 128 pp.

Starr, C. "Benefit-Cost Studies in Sociotechnical Systems." In: Perspectives on Benefit-Risk Decision Making. National Academy of Engineering, Washington, D.C., 1972. pp. 17-42.

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PAGE NUMBER
EPA 287 (Cin)
(4-76)

Starr, C. "Social Benefit Versus Technological Risk: What is Our Society Willing to Pay for Safety?" Science, 165(3899):1232-1238, 1969.

Stradley, M.W., G.W. Dawson, and B.W. Cone. An Evaluation of the Status of Hazardous Waste Management in Region X. EPA 910/9-76-024, U.S. Environmental Protection Agency, Seattle, Washington, 1975. 202 pp.

Talley, R.J., and O.W. Albrecht. "Preliminary Economic Analysis of Hazardous Waste Control." In-house research project, Program Element IDA312, ROAP OIADC. U.S. Environmental Protection Agency, Cincinnati, Ohio, 1974. 79 pp.

Thaler, R., and R. Rosen. Estimating the Value of Saving a Life: Evidence from the Labor Market. Preliminary report for the Conference on Research in Income and Wealth, National Bureau of Economic Research, Inc., New York, New York, 1973.

Tihansky, D.P. "A Survey of Empirical Benefit Studies." In: Cost-Benefit Analysis and Water Pollution Policy, H.M. Peskin, and E.P. Seskin, eds. The Urban Institute, Washington, D.C., 1975. pp. 127-172.

Tihansky, D.P. "A Conceptual Framework for Risk-Benefit Assessments of Hazardous Materials Transport." In: Proceedings of the Fourth International Symposium on Transport of Hazardous Cargoes by Sea and Inland Waterways. CG-D-24-76, Department of Transportation, Washington, D.C., 1976. pp. 103-112.

U.S. Environmental Protection Agency. Decision-Makers Guide in Solid Waste Management. SW-500, U.S. Environmental Protection Agency, 1976. 158 pp.

U.S. Environmental Protection Agency. "Cost-Effectiveness Analysis of Treatment/Disposal Alternatives for Hazardous Wastes." Contract No. 68-03-2754 (awarded to SCS Engineers), U.S. Environmental Protection Agency, Cincinnati, Ohio, in progress.

Waddell, T.E. The Economic Damages of Air Pollution. EPA-600/5-74-012, U.S. Environmental Protection Agency, Washington, D.C., 1974. 167 pp.

Watson, W.D., Jr., and P.B. Downing. "Enforcement of Environmental Standards and the Central Limit Theorem." Journal of the American Statistical Association, 71(335):567-574, 1976.

Zeckhauser, R. "Procedures for Valuing Lives." Public Policy, 24(4): 419-464, 1975.

APPENDIX D

PUBLIC ATTITUDES TOWARD ENVIRONMENTAL ISSUES*

INTRODUCTION

The objective of this literature survey was to obtain a broad understanding of the likely attitudes and behavior of the various parties-at-interest toward situations involved in hazardous waste management. As only one study (Lackey, Jacobs, and Stewart, 1973--see Section 4) has specifically addressed attitudes toward hazardous waste management facilities, a broader scope was necessary. Initially, it was hoped that a study of attitudes toward nuclear power and associated wastes, and toward hazardous waste-generating industries such as the chemical industry would prove fruitful. The intention was to use the chemical industry as a proxy for a hazardous waste management facility and to draw parallels between nuclear power, with its radioactive waste disposal problem, and nonnuclear hazardous waste disposal. However, it appears that there is very little relevant material on attitudes toward waste-generating industries other than nuclear power.

Though there have been many attitudinal studies relating to nuclear power (several of which have addressed the question of nuclear waste disposal), it was concluded that attitudes toward nuclear power would be of very limited value in predicting attitudes towards hazardous wastes, and their management. This is because it appears that the public associates the possible discharge of radioactivity from nuclear power plants and wastes with the effect of nuclear weapons (Pahner, 1976; Louis Harris and Associates, Inc., 1976; Rappeport and Labaw, 1975; Slovic and Fischhoff, no date). While hazardous wastes comprising obsolete chemical warfare and ordnance materials could to some extent pose an analogous type of threat, in general reactions to nuclear facilities appear to be far too extreme to apply to nonnuclear hazardous wastes. Only a very small proportion of hazardous waste would be as combustible as petroleum (which the public appears to readily accept in the form of gasoline), while few would approach the toxicity of materials stored on the premises of a pesticide formulator.

Because the approaches discussed above were unfruitful, the survey was widened to encompass attitudes toward environmental issues in general. Knowledge of such attitudes is useful, as hazardous waste management involves making decisions about the environment--for example, attitudes favoring preservation of natural environments could be expected to correlate with disapproval of ocean dumping. Widening the scope of the survey introduced some difficulties, and caution must be used in interpreting the reported results. Many of the studies used extremely broad or imprecisely worded questions, and consequently it is hard to distinguish between concern about pollution and concern about the environment (which is a broader issue, including resource use, etc.). Unfortunately, the term "pollution" is often used to describe environmental conditions having "unfavorable quality" (Swan, 1973), which suggests that respondents may have considered only the aesthetic or cosmetic side of an issue and not concerned themselves with health or safety aspects. Another difficulty is that quality of the environment may be equated with quality of life (White, 1966). Milbrath's (1975) conclusion that perceptions of environmental quality incorporate views other than those on the natural environment reinforces this concern. Lowenthal (1966), commenting on White's (1966) paper mentions some other pitfalls that may influence findings, as follows. Some people are not always able to present their feelings articulately. Others consider that their environmental preferences should not be subject to scrutiny. Also, people have variable attention spans, which influences what they learn about a situation; thus their opinions may be based on incomplete or erroneous knowledge. Finally, the values inferred from a study are dependent on how the respondents are asked to express them (Dillman and Christenson, 1972).

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* This appendix is based on material prepared by Ms. N.S. Avitable.

Perhaps inevitably there are numerous differences among the results of the various surveys reviewed. In addition to geographic and demographic variations between the populations sampled,* the wording of the questions and the timing of surveys doubtless influenced the responses. Thus the results reported here can probably be used to provide broad indications of views on the environment, but would be inappropriate if fine detail were required.

This appendix attempts to group material by subject category to facilitate easy reference. However, because of varying objectives and the frequent broad nature of individual studies, this often results in a given study being mentioned several times, while the allocation of data to a particular topic is occasionally somewhat arbitrary.

PUBLIC CONCERN FOR THE ENVIRONMENT

Development of Environmental Concern

Concern about the environment is not a recent development. Problems of manmade pollution date back to Roman times (Sewell and Foster, 1971), and conservationists such as James Fenimore Cooper and John James Audubon were active in the early nineteenth century (McEvoy, 1973; Albrecht, 1975; Morrison, Hornback, and Warner, 1972). In the early 1950's, certain dramatic events such as the Donora, Pennsylvania, and the London, England, air pollution deaths caused widespread awareness of the dangers of pollution. By the late 1950's, some air and water pollution-abatement programs were instigated, but these did not receive widespread public support. However, by the late 1960's, the public had become sufficiently concerned about pollution to exert pressure to have something done, and the turnaround in the Nixon administration's environmental policies has been credited to public opinion (Trop and Roos, 1971).

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* Except where indicated otherwise, all the surveys discussed in this appendix attempted to draw representative samples from the local populations.

Heberlein (1972) implies that this sudden growth in environmental concern might be attributed to the moral turbulence of the 1960's and a resulting shift from economics to ethics as a basis for decisionmaking, together with the universal appeal of the environment. This may have caused people to begin to feel responsible for the consequences of their actions. An alternative explanation is that this concern developed as a response to the rapid visible deterioration of the environment (Koenig, 1975). This view is supported by McEvoy (1973), who relates enhanced environmental concern to increased contact with nature (through such activities as camping, etc.), which provided a contrast between relatively unspoiled surroundings and man's generally deteriorating environment. In the early 1970's, interest in the environment was accelerated when the mass media found that it made good copy, particularly as dramatized by "doomsday sayers" such as Barry Commoner, Rachel Carson, and Dennis Meadows (Sewell and Foster, 1971; Downs, 1972; Swan, 1973; Albrecht, 1975). One result was that it became fashionable to be environmentally concerned (Swan, 1973; Morrison, 1973; Means, 1972; Koenig, 1975).

The consensus view of studies conducted in the mid-1970's is that the environment was perceived as being worse at the time of the studies than it had been at any time in the past (Milbrath, 1977, 1975; Althoff, Greig and Stuckey, 1973; Brunner, Gravengaard and Bennett, 1973). Results of one study suggested that recent decay had been most evident to persons in metropolitan areas with populations of more than one million (Joseph M. Viladas Company, 1973). Although many respondents expected the environment to improve in the future, there was pessimism about the degree of improvement and the time needed to achieve it (e.g., Milbrath, 1977, 1975; Brunner, Gravengaard, and Bennett, 1973).

Factors Influencing Environmental Concern

Concern for the environment is not felt by everybody, and the degree of concern varies among those who are concerned. This may stem from man's relationship with the environment. Historically, it has been necessary for man to master the environment merely to survive, let alone prosper (McEvoy, 1973; Albrecht, 1975, 1972). The technology that has helped man do this and that has given him many conveniences has at the same time created pollution (Heberlein, 1972; Swan, 1973). According to Brunner, Gravengaard, and Bennett (1973), it is man's continued desire for the benefits of affluence that has made pollution such a problem. This may have made it hard for many to become more than mildly concerned about environmental conditions. Concern may also be lessened by man's ability to adapt to adverse conditions (Dubos, 1966; Swan, 1973). Means (1972) claims that there are four factors that keep man from changing traditional attitudes (i.e., pro-technology and pro-growth attitudes), and that limit concern. They are: (1) The relationship to nature is assessed in quantitative terms, not qualitative ones, (2) population growth is seen as good for the economy, (3) the present trend toward urban existence separates man from the land and associates him with economic growth, and (4) social mobility further separates man from nature.

The spectrum of attitudes that the public exhibits towards the environment reflects differences between individuals (Maloney and Slovonsky, 1971; Costantini and Hanf, 1972). Concern for the environment is related to attitudes which are a function of such factors as an individual's perceptions, values, priorities and aspirations (Swan, 1973; White, 1966; Albrecht, 1975; Groves and Kahalas, 1975; Klee, 1973). White (1966) identifies four attitude formation factors: The decision situation, the individual's experience with the environment, his perception of his role, and his competence in dealing with its complexity. Munton and Brady (1970, cited by Albrecht, 1975) consider that education is an important factor in attitude development, since it is necessary to be taught what is good and what is bad.

Attitudes are also influenced by needs. According to Maslow, man must first satisfy his physical needs (e.g., food, shelter) before he will become concerned about other needs (e.g., safety, the environment) (Albrecht, 1975; Swan, 1973). This may explain the lack of environmental concern exhibited by people in low socioeconomic groups (Swan, 1973).

The Role of the Mass Media

The mass media can affect an individual's knowledge, as they constitute a source of environmental information (Milbrath, 1975). It was shown by McEvoy (1973) that in the period 1953-69, when there was a growing concern over environmental problems by the public, there was not only an increase in the number of environmental articles (by a factor of 4.7), but a tripling of the number of magazines carrying such articles. McEvoy's review of a study by Russell (1970) indicated that most of this increase was in articles dealing with the urban environment. Munton and Brady (1970) noted a dramatic increase between 1964 and 1969 in the number of letters-to-the-editor of the New York Times on environmental problems. These authors also demonstrated a similar increase in the coverage devoted to environmental matters by the New York Times, and they concluded that public concern was at least partly explained by the attention given to environmental matters by the mass media (Munton and Brady, 1970).

O'Riordan (1971a) found a high degree of awareness regarding a sewage disposal issue in his study. He attributed this to the influence of the local newspaper, as more than 65 percent of his interviewees said it was their most important source of information. On the other hand, data in one of Milbrath's (1975) surveys indicated that the public perceived themselves to be poorly informed about environmental problems.

The amount of space given by the media to a topic depends on how newsworthy it is felt to be. In a basically rural state (Kansas) the environment was not seen as particularly newsworthy (Althoff, Greig, and Stuckey, 1973), even though a majority of media managers felt it was a real problem. On the other hand, Maloney and Slovonsky's (1971) survey of editors in areas with high air pollution found the environment to be an important news item mainly because pollution was a serious problem that affected everyone and that had become a political issue. Although pollution is seen as a local problem, only the larger newspapers obtain most of their information from local and state governmental agencies. The smaller ones rely on the wire services, a fact which influences the nature of their coverage (Maloney and Slovonsky, 1971).

No matter how newsworthy the environment is felt to be, Maloney and Slovonsky (1971) indicate that the effect of coverage depends on audience predisposition, and that interpersonal relationships contribute most to the shaping of public opinion. This view is supported by the work of Sharma, Kivlin and Fliegel (1975). Respondents in their sample indicated that they did not use information from the local newspaper to influence their opinions about local pollution. In some instances, the news media may add to existing anxiety by its enthusiastic coverage of an issue. For example, media bombardment heightened the controversy over radiation in the early 1960's.

Who Is to Blame for Pollution?

The public does not attribute pollution to any one preeminent cause, although industry is often rated as a major source. Respondents believe that the blame can be shared by the public, emphasis on growth, and a lack of planning (Erskine, 1972a; Milbrath, 1975, 1977; National Analysts Inc., 1972; Langowski and Sigler [Belden #2 study],* 1971; Murch, 1971; Dunlap, 1975).

The results of various studies indicate that different groups emphasize different sources. Analysis of data presented by Milbrath (1975), found the public to give the highest mean-cause ratings to industry and its own carelessness (first and second) out of several possible causes. In contrast, community leaders rated lack of long-term planning and high consumption as causing the greatest amount of pollution. Dunlap (1975) found that Democratic and liberal students blamed emphasis on growth, while Republicans and conservatives blamed society's habits and desires. This may be indicative of the nonbusiness versus business emphasis of the groups, although it could be two ways of saying the same thing. The response frequencies from the 1970 Opinion Research Corporation survey (cited by Erskine, 1972a)† showed the chemical and oil industries receiving the greatest amount of blame. Yet, closer inspection of the data indicates that people put most of the blame on what is familiar. For example, people in urban areas blame industry and automobile emissions, while those in rural areas blame dust and insecticides. Finally, 45 percent of the respondents to a 1972 Harris poll said pollution was the biggest problem created by science (Erskine, 1972a). However, Taviss (1972) found that opinion was divided over the inevitability of technology causing pollution.

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* Langowski and Sigler abstracted data from several surveys, most of which were unpublished.

† Erskine reproduces data from various surveys, and does not provide specific citations for these surveys.

How Can Improvement Be Effected?

Questions about how the environment can be improved are usually multiple response questions, and there is often no consensus solution. In one study (Murch, 1971), almost half the respondents either skipped the question or said that they could not decide. A frequent response has been to suggest government control at some level--local, state or Federal (Althoff, Greig, and Stuckey, 1973; National Analysts, Inc., 1972; Langowski and Sigler, 1971; Milbrath, 1975). Other suggestions have included controlling auto exhausts and industrial wastes (Erskine, 1972a) by individual effort (National Analysts, Inc., 1972; Koenig, 1975; Langowski and Sigler [Belden #1 study], 1971) and through advanced technology (LaPorte and Metlay, 1975).

A majority of the Democrats and liberals in Dunlap's (1975) student sample felt that a significant change would be needed in our sociopolitical structure for environmental improvement to occur. The Republicans, moderates and conservatives felt that a solution could be obtained within the present system. Dunlap and Gale (1974, cited by Albrecht, 1975) suggest that this is because the Republicans are business oriented, and are therefore not likely to want government intervention or control. The need for sociopolitical change also appears to be favored by many environmentalists (Morrison, 1973).

Environmental planning with public involvement was an acceptable solution to a majority of Milbrath's (1977) respondents. However, industrialists were split equally between public involvement and leaving planning to the specialists. When the public was asked if it still wished to have planning as opposed to certain freedoms (e.g., to do what they wish on their own property), the percentage in favor of planning decreased slightly. Those in areas not expected to experience economic growth and low income whites were most likely to favor freedom. Environmentalists and developers, however, were uncompromising in their views.

For another group sampled by Milbrath (1975), pollution elimination (air and water), obtaining adequate energy supplies, educating the public, and land use planning were at the top of the priorities list for improving the environment. Individuals' perceptions of the adequacy of present efforts in solving the problem affect their estimates of the future kind and level of effort needed to obtain results. Most of those in rural areas appeared to be satisfied with present efforts, whereas most of those in industrial areas found them inadequate. Community leaders tended to see existing efforts to be more effective than did the general public, but it was suggested that this might be because they themselves were usually involved in these efforts and thus were more aware of progress. Of all the solutions suggested, more of the public were willing to rely on technology than were the leaders, and a majority of both groups saw a need for some social change (Milbrath, 1975).

There appear to be no well defined attitudes regarding the amount of enforcement needed to make environmental policies effective (Joseph M. Viladas Company, 1973). The results indicated that strict enforcement is more likely to be favored by those who are the most concerned about the problem, those living in metropolitan areas, and those seeing their environment as least good. Also, the more a person was willing to pay to reduce pollution, the greater the enforcement he desired. However, the researchers concluded that where people were faced with the facts, they first balanced the cost of pollution abatement against its benefits and then took a stand.

The Relationship Between Concern and Action

Attitudes are not directly related to action; they may only establish a predisposition to behave in a particular manner (Otway and Fishbein, 1976; White, 1966). The action that an individual takes regarding a problem depends on the concern he has about the problem and its priority in his life, and on what he feels he can do (Swan, 1973; Costantini and Hanf, 1972). Responses to risk situations depend on how the individuals interpret the potential perils (real or imagined) and the benefits, if any (Maderthaner et al., 1976). For example, one person may fear that the nearby location of a chemical landfill could lead to his death from some accident, whereas his neighbor may see the landfill as a source of employment. Pahner (1976) in a paper discussing societal responses to technological change (primarily nuclear power) concluded that individuals learn to construct and perceive their environment in such a way as to reduce their anxiety. Everybody needs to feel secure, and when anxiety is intense enough, action results.

Although the operation of the National Environmental Policy Act calls for citizen input to environmental decisions (Smith, 1973), this has not led to significant public participation in many situations. A common pattern is that a first decision is made with little public input, even though a special interest group may have been responsible for the pressure that led to the decision. This is then followed by some kind of action because people do not like the decision (O'Riordan, 1971a). Milbrath (1977) feels this lack of participation may be a result of inadequate media emphasis and the fact that people do not have a sustained interest in the issue.

In 1972, Downs demonstrated how the environment fits into the "issue-attention cycle" that the public appears to follow on domestic problems. He suggested that interest intensity would decline as the public realized how difficult, and especially how costly, it would be to solve environmental problems (Downs, 1972; also see Sewell and Foster, 1971). However, Downs noted that once a problem has been prominent, it can easily recapture attention. This is not inconsistent with Mitchell's (1978) claim that the environment is an enduring concern.

Although most of those interviewed by Murch (1971) said they would consider the pollution issue when voting for candidates for public office, action on environmental issues is usually initiated by special interest groups who attempt to influence decisionmakers or others who can have an impact on decisions (O'Riordan, 1971a). Draper (1973) implies that action groups emerge because people feel remote and their voices can only be heard in this manner. In meetings held regarding sanitary landfills, Klee (1973) found that the percentage of the public attending was higher for those in rural areas than urban areas. Similar turnout levels were found for urban

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ethnic and working-class areas. Objections were usually raised by ad hoc groups.

Studies of individuals involved in environmental activities have found that such people were more knowledgeable about the environment and less optimistic about what could be done than those who were relatively inactive (Levenson, 1974; Milbrath, 1975). Those involved also had a higher level of education, more complex belief structures, were more aware of and concerned about the problem, and felt it to be more serious and in urgent need of a solution than others (Milbrath, 1975). Milbrath's study found that most of the activities in which individuals said they participated were of a personal rather than political nature. Generally, people in his sample felt a higher level of responsibility to engage in such behavior than they actually did, but they were less inclined to feel a need to participate in politically oriented activities than personal ones.

Trigg et al. (1976) studied the anti-pollution behavior of "internals" (those who believe their rewards are dependent on themselves) and "externals" (those who believe their rewards are dependent on outside forces). They found that optimistic internals had the highest mean number of anti-pollution activities and optimistic externals the lowest. The two pessimistic groups were in the middle, with an equal mean number of activities.

In some cases, environmental intervention has led to positive results. For example, Commonwealth Edison's (Illinois) stepped-up program to clean the air (Maloney and Slovonsky, 1971), and the prevention of a West Virginia firm from disposing of their chemical wastes in Louisiana (Mackay, 1976). There has also been a shift in the burden of proof requirements from those environmentally concerned to the proponents of development (Goldman, 1973). Thus it is now the developers who have to show that a project will not cause unacceptable environmental degradation, whereas previously the converse was true.

In other cases, however, public concern has accomplished little. The Reserve Mining case has received much attention, but while protest action started in 1969 (Carlson, 1975), the problem has only recently been resolved. In 1978, the Reserve Mining Company obtained the necessary permits to use land disposal for its asbestos-bearing taconite tailings, scheduled to commence in 1980. (Telephone interview, A. Samuel, Reserve Mining Company, Silver Bay, Minnesota, August 7, 1978.) Carlson concluded that the concerns of the citizens (over the quality of their drinking water) had difficulty in competing with economic considerations. She implied that the Reserve Mining Company was using delaying tactics in the hope that the public would tire of the issue and to delay any costly remedial actions such as land disposal (Carlson, 1975). In a similar situation, although concerned about sewage seeping into a local lake, most of O'Riordan's (1971a) sample had not bothered to become involved in any action that could change the situation, as they felt that they would not be able to influence the political system.

Furthermore, it appears that people do not necessarily take avoiding or mitigating action, even where the appropriate action (at least as a precaution) is obvious. Data from a pilot study done in Duluth, Minnesota, on people's attitudes and behavior regarding asbestos fibers in their drinking water (originating from the Reserve Mining Company's taconite tailings)

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were not encouraging. The vast majority still appeared to be using this water for everything (Franz, 1976).

ATTITUDES AND BEHAVIOR OF SPECIFIED PARTIES

The General Public

Level of Concern--

Concern over the environment varies from none to a great deal, while the public's perception of pollution as a problem ranges from little or none to very serious. When asked about the most important problem facing the United States today, pollution generally is ranked behind such areas as the state of the economy and crime; i.e., it is not the top priority (Koenig, 1975; Brunner, Gravengaard, and Bennett, 1973; National Analysts, Inc., 1972; Milbrath, 1975; Dillman and Christenson, 1972; Erskine, 1972b; Mitchell, 1978; Trop and Roos, 1971; Joseph M. Viladas Company, 1973). Between 1965 and 1970, public opinion polls such as those conducted by Harris, showed a dramatic increase in concern over the problems of air and water pollution (Erskine, 1972b). A review of polls from 1970 to about 1977 by Mitchell (1978) found that although there was an increase in "very serious" as a response to questions about the seriousness of the pollution problem, there was a decrease in the proportion of those responding "pollution" to the open-ended question of "What are the important problems that we are faced with today?"

Concern about pollution does not necessarily correlate with the levels of pollution experienced. Ludwig, Morgan, and McCullen (1970) analyzed survey data and found that concern for such things as air pollution had risen in a broad sample of urban areas, although the levels of common pollutants had declined. This has been attributed, at least in part, to the attention being given by the mass media to pollution (Albrecht, 1975).

Relationship Between Concern and Demographic Characteristics, Etc.--

The perceived seriousness and concern felt about pollution and the environment has been studied in relationship to various demographic and personality characteristics. There is a consensus that high levels of both perceived seriousness and concern are exhibited by the young, those with high incomes, those with a high level of education (usually some college and above), and those who are classified as professional (white collar) workers (Winham, 1972; Brunner, Gravengaard, and Bennett, 1973; National Analysts, Inc., 1972; Trop and Roos, 1971; Langowski and Sigler, 1971; Joseph M. Viladas Company, 1973; Tognacci et al., 1972).

There also appears to be a rural/urban dimension (Althoff, Greig, and Stuckey, 1973; Erskine, 1972b; Milbrath, 1975). The greatest concern is exhibited by those in large metropolitan cities (Sigler, 1973; Trop and Roos, 1971; Langowski and Sigler, 1971; Joseph M. Viladas Company, 1973). A review of the polls presented by Erskine (1972b) showed the following patterns: The most concern or awareness was in suburban areas, followed by the core cities, then semirural areas, with the least being shown in rural areas. This pattern was consistent, no matter how the interview questions were phrased. However, at least one study (Koenig, 1975) did not find this dimension. The rural/urban dimension may actually reflect some obvious differences between rural and urban dwellers. Rural people are most likely to be directly or indirectly dependent on natural resource industries (including agriculture) for their livelihoods, and to be exposed to lower levels of pollution than urban dwellers. According to a recent analysis by Tremblay and Dunlap (1978), this hypothesis is supported by study data which show that the urban/rural dimension cannot be accounted for by age, income or educational differences.

Some evidence supports a regional factor. Erskine's (1972b) poll review found that people in the South were consistently low in their concern and awareness responses. Trop and Roos (1971) feel that this is due to the fact that there is little industry in the South, and that these people have a tradition of States rights.

Dillman and Christenson (1975) studied the association between concern about pollution, the extent to which various types of corrective actions were desired (e.g., more government spending), and the actual level of air pollution. The results showed that the higher the pollution level the greater was the concern, as did the analysis of Tremblay and Dunlap (1978). Dillman and Christenson (1975) also found weak correlations between concern and activities desired, but correlations between these variables and demographic and community identification characteristics were inconclusive. These findings led Dillman and Christenson to suggest that people accommodate to pollution.

People tend to view pollution as being worse elsewhere than at home (Murch, 1971; Milbrath, 1975; Langowski and Sigler, 1971; Tremblay and Dunlap, 1978), although Winham (1972) found that Hamilton, Ontario, residents rightly perceived the pollution problem to be worse in their own community than in other parts of Canada. Murch's (1971) respondents not only did not believe that pollution was as bad a problem in their city (Durham, North Carolina) as elsewhere, they also perceived it as less severe in their neighborhoods than in the rest of the city. Murch attributed this to the media's concentration on national environmental problems and not local ones. This tendency by residents to discount local pollution (unless the problem is really bad) was analyzed by Milbrath (1975), who suggested that many people live as close as they can to their ideal locale. Consequently, they find it difficult to perceive that where they are living is worse than anywhere else. There is some indication that an individual's view of pollution in his community is correlated with whether or not he is an established resident, which tends to confirm Milbrath's suggestion above. Sharma, Kivlin, and Fliegel (1975) found that longtime residents in their study did not view the problem as seriously as others. Murch's (1971) more committed residents (e.g., those owning homes) also tended to most underestimate the problem.

Perceptions also tend to be based on what individuals are used to. This is illustrated by the rating given to drinking water by citizens in two neighboring Georgia towns using water from the same stream. Citizens from one town found the water satisfactory while the other group of citizens found it unsatisfactory. The unsatisfied residents sometimes received water from an alternative source with a less pronounced taste, whereas the satisfied group only drew water from the source branded as obnoxious by the displeased citizens (White, 1966).

Political ideology has also been found to have some influence on views on the environment. In general, the more liberal a person is, the more concerned he seems to be (Koenig, 1975; Tognacci et al, 1972; Dunlap, 1975; Dunlap and Gale, 1972). Dunlap's (1975) study of students at the University of Oregon found that liberals not only saw pollution as being more serious than did the conservatives, but also expressed greater interest in environmental issues, gave greater approval to associated movements, and were more likely to have been involved in some kind of environmentally related action.

Other Factors in Environmental Concern--

There are conflicting findings on the relationship between the concern shown and an individual's understanding of the environment. Swan (1973) found no relation between concern and knowledge, and Milbrath (1975) found that though over 90 percent of those sampled had some environmental concern, a majority had no environmental knowledge, or knowledge that was only superficial. Other work in this area by Trigg et al. (1976) found internals (i.e., those who believe they can have some effect on outcome) to know more about pollution and the environment than their external counterparts. Koenig's (1975) findings showed individuals favor the same type of action for both environmental and socioeconomic concerns, whereas low environmental concern has been related to fear of job loss (Winham, 1972) and to residence in poor areas and lack of awareness (Trop and Roos, 1971).

Little research has been done on the hypothesized relationship between contact with the environment through recreational activities and environmental concern. Dunlap and Hefferman (1975) found that participation in outdoor activities, whether consumptive (e.g., fishing) or appreciative (e.g., camping), was weakly related to concern for issues relevant to that particular activity.

Results of a study by Foote, Cone, and Belding, Inc. (in Langowski and Sigler, 1971) showed that a majority of people with eye, nose, throat and breathing problems blamed pollution for them. Investigators at the Joseph M. Viladas Company (1973) found that for 11 of 13 causes of pollution, people rated damage to their health as being greater than damage to the environment. They suggested that these results may have been influenced by use of the anxiety-producing word "health." The damage ratings given to each of the causes in this study indicated that the respondents perceived visible pollutants (e.g., air emissions) as causing the most environmental damage. These researchers calculated a concern score for each respondent based on the number of items he felt caused "a lot" of environmental damage. This score generally correlated with an individual's perceptions of his environment.

Orr (1974) studied the relationship of two concepts of alienation--i.e., powerlessness and anomie (which is the absence of norms), to attitudes to the term "sewage treatment" and to the concept of a "local anti-pollution bond referendum." The research was carried out in a small town where sewage treatment activity (planning/construction) was in progress. In general, he found that those who were most alienated were most opposed to the referendum concept but were less opposed to sewage treatment than less alienated individuals. He also found that anomic people tend to evaluate the term "sewage treatment" negatively.

In a longitudinal study, Donohue, Olien, and Tichenor (1974) surveyed the residents in four Michigan communities (Duluth, Ely, Silver Bay and Grand Rapids) in 1970 and again 18 months later in 1972. They found that accurate knowledge on three local environmental issues had decreased, as well as had the support for the belief that technology could solve the problems. People were turning their attention to the (adverse) consequences of control of environmental quality and were more likely to believe that the issues had been given too much attention. Residents felt that the burden of resolving the environmental problem had shifted from the individual to the firms involved and to public agencies, and in three of the four communities there was reduced willingness to pay additional taxes. The investigators concluded that attitudes are affected by community structure and issue remoteness. Large communities tend to be more concerned and more willing to accept necessary controls than small ones, which are faced with a trade-off involving development values.

Attitudes to Specific Environmental Issues--

Some research has been done on attitudes toward certain specific environmental issues. In one such study, Salcedo et al. (1971) investigated attitudes toward the pesticide industry. They found what they called a rural/urban dimension, but examination of the results indicates that "agriculture/non-agriculture" might be a better description, as farmers possessed more positive attitudes towards the pesticide industry than city and town dwellers.

Langowski and Sigler's (1971) survey of studies found that as distance to a sanitary landfill decreased, the percentage of people with negative attitudes increased. Klee's (1973) review of several EPA studies about sanitary landfills showed that the nature of opposition to landfills is influenced by community social status. Low social status communities are worried about becoming a "run-down community," whereas those with higher status are primarily concerned with nuisance and, to a lesser extent, property values. Twenty sanitary landfill siting proposals were reviewed and protest was found to be strongly correlated with visibility. In turn, the success/failure of the proposal was found to be related to protest and location (in or out of the community it was meant to serve). Seven of 15 protested and all nonprotested proposals were successful. However, only one of seven outside proposals was successful. Communities do not want to be garbage dumps for others. In another study reviewed by Klee, it was found that there was a low general level of awareness about solid waste disposal activities, although awareness increased when controversy was present. Low awareness of the nature of environmentally adequate waste disposal activities may explain why negative attitudes to waste appear to be transferred to related correction proposals, such as sanitary landfills.

Summary--

O'Riordan (1971b) discusses public involvement in environmental issues, and lists a number of factors that inhibit the clear expression and political

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articulation of public preferences about the desired quality of the environment. This list, which is reproduced below, points up many of the aspects already discussed.

> (a) People rarely act until they are directly affected and threatened;
> (b) People rarely help each other unless they are bound by a common cause or faced with a common threat;
> (c) People become tolerant of gradually worsening situations and are able to develop a number of defensive social psychological and behavioral mechanisms which help them to accept or avoid the full intensity of the deteriorating environmental impact;
> (d) People are environmental gamblers discounting heavily any future uncertainties for the transitory pleasures of immediate gains;
> (e) People are schizophrenic with regard to the environment because they are usually unaware of the delicate interactions linking the various environmental subsystems, and will pollute on the one hand and yet demand increased environmental quality on the other;
> (f) People are confronted with all sorts of personal and community problems in life and always delay the difficult decisions hoping that when they have to be faced, solutions will be easier to find and decisions easier to make. Thus people tend to leave the most complex decisions to the politicians and the experts, yet are surprised and not infrequently annoyed when they do not always come up with the right answers in the absence of a clear expression of public desires;
> (g) People play a variety of roles in their economic, social and political lives, and frequently a number of these roles conflict simultaneously. This tends to distort the rational reasoning process and may lead to an inconsistency of attitude toward environmental phenomena. For example, the president of a large paper mill polluting a river may also be a director of a local community organization pressing for an off-river swimming pool to protect his children from a possible health hazard. We see here clearly the conflict of values and resulting inconsistent actions of an individual who is playing simultaneous roles as a private *entrepreneur* and as a socially concerned *citizen*. (O'Riordan, 1971b:101)

Leaders

Leaders are those people who are probably in a better position than the general public to have an impact on environmental decisionmaking and on the environment itself. They include businessmen, politicians, and industrialists. Some researchers have put environmentalists in this group, but they will be treated separately in this appendix.

Like the general public, leaders tend not to see the environment as the main problem facing the nation. Miller's (1972) survey found them more concerned with such issues as race relations, unemployment and poverty.

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Sofranko and Bridgeland (1975) theorize that leaders (e.g., mayors, who downplay environmental problems) do so because they feel they need to maintain a good community image.

There is not always agreement between leaders and the general public. Although there was some basic consensus on water quality issues and causes, and need for environmental planning, Milbrath (1977) found the two groups to rank the remaining water problems and related causes differently, with the public being more pessimistic about regional (Niagara Frontier in New York) water quality than the leaders. In another survey carried out in the same area, Milbrath (1975) found leaders to be more aware of "the environmental problem" and able to see the problem more as a long-range threat than the public. Leaders in urban areas saw the environment as being worse than perceived by the general public, while the reverse was found in rural areas.

In two studies, Milbrath asked leaders how they thought the general public would respond to certain questions, and compared their estimates with those actually received. In one of the studies, although not generally accurate, elected leaders were found to be fairly good in predicting which government body should be responsible for water quality, that the government should do some environmental planning, and that people prefer freedom to planning (Milbrath, 1977). In the second, the leaders were correct in predicting that the public saw pollution as a component of the environmental problem, that they put the blame on industry, and that they prefer economic growth and jobs to control. However, the leaders did not think the public would perceive the environmental problem to be as serious as they did, and they incorrectly predicted them to desire better gas mileage over clean air (Milbrath, 1975). Milbrath inferred that leaders' estimates of the public's views might be based on media presentations. There was also some indication of self-consciousness on the part of the leaders, as they thought that the public would find ineffective government to be an important cause of the environmental problem, whereas the public had a low mean rating on this item (Milbrath, 1975). Jensen and Stormes (1971, cited by Klee, 1973) also found that officials were not very accurate in their perceptions of citizens' rankings of reasons for objecting to sanitary landfills.

Costantini and Hanf (1972) surveyed only those who could have an impact on decisionmaking in the Lake Tahoe area, and determined a score on a scale that they developed for environmental concern. This score was found to be positively related to the sense of urgency felt for the area's problems, the amount of response action an individual would support, the importance placed on the issue of environmental degradation, and the level of education. The environmental score correlated negatively with the emphasis placed on the area's environmental problems and with length of residence. Those in the high concern group rated the urgency of quality problems (e.g., deforestation) greater than that of practical problems (e.g., traffic congestion), were pessimistic about the environmental future, and tended to be professionals or government officials (particularly Federal). They also tended to have no faith in local government, to value rural life, to have great aesthetic appreciation, and to be critical of technology. Those in the low concern group saw practical problems as more urgent, tended to perceive the environment in functional or utilitarian terms, were more likely to be businessmen or local government officials, and were more likely to have conservative political views. There was no correlation with socioeconomic status, possibly because the sample was almost exclusively middleclass. Respondents who defined the environment in natural terms saw the Lake Tahoe area as being more polluted than those who keyed onto health hazard aspects. The apparent lack of concern by local officials was cited as the reason why people had turned to outside help for their environmental problems.

Carter et al.'s (1974) national survey of city (population $\geq$ 10,000) and county (population $\geq$ 50,000) governments included the following findings. There was no consensus on a definition of environment; the two levels of government rated problems differently as to their severity, but the more severely a problem was seen, the more likely it was that something would be done to correct it. A regional and urban/rural dimension was also detected, with the environment being rated the most important problem in the West, and in the suburbs followed by the core cities.

Environmentalists

Environmentalists, or "protectionists" as they are sometimes called (Milbrath, 1975), can be characterized as generally having higher levels of education, income, and occupational status than the general populace (Albrecht, 1975; Morrison, Hornback, and Warner, 1972; Milbrath, 1975; Morrison, 1973). They tend to live in newer, better kept homes in better neighborhoods and to like an outdoor lifestyle (Milbrath, 1975). It has been suggested that their education allows these people the conceptual tools with which to better comprehend environmental problems, and that their higher levels of income not only make them economically independent of industries that might conflict with the environment, but gives them the leisure to cultivate aesthetic values and be environmentally involved (Albrecht, 1972, 1975); Morrison, Hornback, and Warner, 1972; Morrison, 1973). Morrison, Hornback and Warner (1972) found that their sample of environmentalists contained a large number of young persons, which they attributed to general student activism and to the students' instructors being part of the elite (leader) group described above.

Responses of protectionists in Milbrath's (1975) survey indicated that they believed environmental quality to be low and that they saw the environment as not just one issue, but as an interrelated set of problems. They saw the causes of the problem as basically economic and social in origin (e.g., high consumption, lack of planning). They were more likely to blame technology and to be more pessimistic about future improvement. Environmentalists tend to be anti-growth (Milbrath, 1977; Albrecht, 1972). One Milbrath (1977) study found that though environmentalists believed that community rule was preferable to individual rule and strongly favored planning, they thought it should be at a regional rather than local level. A majority believed that we can have both jobs and a clean environment, and that money (e.g., from taxes) should be spent on environmental improvement. Milbrath (1977) found that environmentalists were not at all close in predicting the attitude of the general public on matters of planning versus freedom, on a jobs vs environment compromise, and on the growth issue. In fact, they appeared to perceive the public as holding almost exactly opposite views to their own!

All environmentalists are not alike (Morrison, Hornback, and Warner, 1972), probably because of individual value preferences. Schnaiberg (1971, cited by Albrecht, 1975) has classified them into four groups. The first group (which he calls "cosmetologists") is made up of those who deal only with the by-products of consumption, and are rather superficial in their outlook. They relate well to activities like anti-littering campaigns and tend to be well liked by the pollution generators. The second group is the "meliorists," who focus largely on consumption-related activities and resource recovery. Schnaiberg calls the third group "reformists." This group perceives the relationships between consumption and production and environmental decay and is more knowledgeable about the physical/biological processes involved. Reformists attempt to influence decisionmaking, and instead of focusing on litter and recycling, they are likely to oppose auto pollution, dam construction, nuclear power facilities, etc. Finally, there are the "radicals," who aim at a total restructuring of the social and economic system. Radicals do not separate environmental problems from the corporate or industrial state, and its attendant inequalities (Schnaiberg, 1971, cited in Albrecht, 1975). Though this range in orientation of environmentalists is very wide, implying a wide range of tactics, Gale (1972) argues that to date most action has been within the confines of middle-class politics, such as lobbying, petitions, and court suits. (These are the tactics of the reformists, who probably have the greatest potential to influence hazardous waste management decisions. Consequently reformists are emphasized when the behavior of environmentalists is discussed in the main text of this report.)

The dramatic growth in membership in environmental organizations that occurred in the late 1960's (McEvoy, 1973) has slowed somewhat. One reason is a shift in concern of many such groups from recreational interests to general environmental quality issues (Faich and Gale, 1971, cited by Albrecht, 1975) and to problems of resource depletion (Morrison, 1973). In some cases, this has put recreationalists at odds with preservationists (Albrecht, 1975). Another reason is that it has become apparent to many that some costs will be necessary to reach their goals. Although some expenditures will only be incurred over the short term, they may be substantial in dollar magnitude; other costs may be incurred in terms of lost personal freedoms and the added social complexity inherent with new laws. Along with this shift in focus has come a shift in strategy--from participation (e.g., Earth Day) to power (to coerce change) (Morrison, Hornback, and Warner, 1972).

Growth-oriented Groups

It is not surprising that the anti-growth attitudes of the protectionists have engendered the formation of opposition groups sometimes called "growthists" (Albrecht, 1972). These opposition groups comprise both specific interests threatened by environmental action and disadvantaged groups (e.g., blacks, working class) who hope that continued growth will help them overcome their current status (Morrison, 1973; Buttel, 1978). It is interesting to note that Milbrath (1977) found that it was not industrialists, but developers who were more likely to favor growth.

These growth-oriented groups have mounted counterattacks of two kinds. The first is that of implying that the environmental movement is part of a larger conspiracy (i.e., communism). The second uses scare tactics such as implying that job loss is inevitable if certain pollution prevention policies are instituted (Albrecht, 1972). The classic economy/environment trade-off provides good examples of the development of growthist groups. When environmentalists were successful in blocking power plant construction in the economically depressed Southwest, a pro-growth movement developed. These people were willing to take chances with the environment to obtain the economic benefits that would come from the construction and operation of these plants (Albrecht, 1972).

Industry

Not only has industry received a great amount of blame for pollution, it has also been accused by some of not doing very much about it (Erskine, 1972a; Althoff, Greig and Stuckey, 1973). In response, corporations have included accounts of what they are doing to protect the environment or return it to its natural state in their annual reports and advertisements (see Fry and Hock, 1976).

Industry, according to a 1970 survey of "Fortune 500" company executives (Diamond, 1970), was worried that under public pressure (they do not feel that environmentalists represent the public), government will set standards that could hurt it financially. However, these executives were not inherently opposed to Federal regulation of activities and indicated that they would particularly like to see programs instituted that include tax incentives. They felt that any action taken should be on an industry-wide basis so that competition would be maintained. Some executives, mostly those in the South or with transportation utilities, would prefer regulation by local governments. Although a substantial number of large firms had budgeted for anti-pollution activities, their executives said that pollution control was not a top priority problem.

THE ECONOMICS OF POLLUTION ABATEMENT

It is evident that all actions to improve the environment will cost something. The cost may be a conventional economic cost, or it may only be a cost in terms of time and inconvenience. Some surveys have asked who should take responsibility for reducing pollution. Langowski and Sigler's (1971) review found that people felt financial responsibility rested primarily on industry. This finding receives some support from Eastman, Randall, and Hoffer (1974/75). Their survey in the Four Corners Region (which has a number of power plants and mining operations) found that Indians living on reservations felt that financial responsibility lay with the producers and users. Many of these respondents were not users of electricity. A majority of nonreservation residents and tourist/recreationists felt that the responsibility lay with a combination of electricity users, producers, local residents, and recreationists.

Many survey respondents favored more government spending on pollution abatement. Others felt a combination of all three parties involved--industry, government, and consumers--should be responsible (Erskine, 1972b; Mitchell, 1978; Dillman and Christenson, 1972, 1975).

Willingness-to-Pay for Pollution Abatement

Most people are willing to pay some amount for environmental improvement, even if they do not feel a responsibility to do so (Eastman, Randall and Hoffer, 1974/75; Milbrath, 1975). Since 1965 there has been an increase in this proportion, and by 1971 they represented more than 50 percent of those polled (Erskine, 1972b). During this same period of time (1965-1971) there was a drop in the number of people willing to allow tax incentives for industry (Erskine, 1972a).

Willingness-to-pay may be in the form of higher electric bills or a higher fee for use of recreational facilities (Eastman, Randall, and Hoffer, 1974/75). In some cases, an increase in taxes seems to be an acceptable means of providing necessary pollution control funds (O'Riordan, 1971a; Milbrath, 1977; Murch, 1971). However, some would prefer higher prices (Joseph M. Viladas Company, 1973; Mitchell, 1978), and others would accept more regulation (Milbrath, 1977).

Of course, not everybody wishes to increase his out-of-pocket expenses to improve environmental quality. Some would prefer to take personal action, such as to carpool or source-separate wastes. For example, 90 percent of the housewives interviewed by National Analysts, Inc. (1972) said they would perform in-home source separation of wastes rather than pay even a minimal fee to have this done by the municipality. It should, however, be noted that intentions do not always translate into action. Although this sample of housewives was concerned about the solid waste problem, it turned out that very few had actually done anything about it (National Analysts, Inc., 1972). This sort of discrepancy had been noted elsewhere. In the Brunner, Gravengaard and Bennett (1973) study in Toledo, Ohio, 61 percent of the respondents said that they would be prepared to use unleaded gas, and 41 percent said that they would ride the bus to reduce pollution. But only 24 and 23 percent, respectively, showed any sign of acting on these intentions.

The dollar sums that individuals are willing to pay to abate pollution or to protect the environment vary widely. For example, Milbrath (1975) found that about half of his respondents were not prepared to pay anything to protect the environment. Other responses ranged up to $415 per month, with about 20 percent of the respondents prepared to give up more than $25 per month. In a 1973 nationwide study, the Joseph M. Viladas Company (1973) found that the average amount volunteered to reduce auto pollution was a capital expenditure of $62 per car and an operating expenditure of $27 per year. To reduce air pollution from electric power plants, people volunteered to pay an average increase of 22 percent (or $3.84) in their monthy electricity bill. They were also prepared to pay $37.43 per year to eliminate water pollution from food processing and an extra 15 percent to recycle solid waste. O'Riordan's (1971a) respondents were prepared to pay a 12 percent increase in local taxes to prevent the seepage of sewage into a local lake.

Those with the highest incomes and the greatest concern are generally willing to pay the most to insure environmental quality (Joseph M. Viladas Company, 1973; Milbrath, 1975; Auld, 1974). One study found the amount to be strongly affected by the interaction of income and concern (Joseph M. Viladas Company, 1973). The amount has also been found to be directly related to socioeconomic status and the degree of understanding of the environmental problem, its ramifications, and potential solutions. More whites than blacks, more males than females, and more of those active in environmental groups than not were willing to pay something (Milbrath, 1975). Other factors found to affect willingness-to-pay were awareness of the EPA (Joseph M. Viladas Company, 1973), level of education (particularly in industrial settings) (Auld, 1974) and perception of the seriousness of the problem (Murch, 1971). Auld (1974), found that the sum that an individual was willing to pay was inversely related to age. However, the Joseph M. Viladas Company (1973) found that the young and the old were prepared to spend the most, which they attributed to the fact that these people are on the low commitments parts of the "life cycle of family spending." In one study, the sum was found not to be related to proximity to pollution (Auld, 1974). In all the studies reviewed, data suggest that people are most willing to pay an amount of money that will not significantly reduce their standard of living.

The rural/urban and regional dimensions again appeared in analysis of data regarding the amounts people were willing to pay. Evidence indicates that people in the South and in small towns and rural areas are willing to pay slightly less than those in other areas (Erskine, 1972b). However, one of Milbrath's (1975) studies found those in rural areas willing to pay more than those living in cities, suburbs, and towns.

Trade-offs with Business and Growth

Costs of protecting the environment could also be in the form of a decline in economic growth or a loss of jobs. The proportion of those in favor of closing a polluting plant is low (particularly in the industrial East) when a job loss is associated with such an action (Erskine, 1972a). One study found that unless there was some kind of government assistance for those losing jobs to find new employment, people had difficulty deciding that a plant should be shut down (Joseph M. Viladas Company, 1973). They concluded that lack of contact with such a situation would make it hard for people to give a valid answer to this type of question. Thus it is easy for somebody to be in favor of closing a plant when the consequences will not affect them, but it is hard for an individual to support such an action if he will himself suffer an economic loss as a result. A recent review by Mitchell (1978) illustrates this difficulty. Though 42 percent of the respondents to a survey favored jobs and 29 percent said it was more important to reduce pollution, 18 percent said both were important. However, most of those interviewed by Milbrath (1977) felt that improvement of the environment would create jobs, thus no economic trade-off would be necessary. In his other survey, he found 43 percent in favor of jobs and 25 percent preferring environmental protection, the remainder being undecided or seeing no trade-off as necessary (Milbrath, 1975).

In a survey of residents in a community where the closure of a water-polluting meat packing plant was likely, Sharma, Kivlin, and Fliegel (1975) found a low positive correlation between intolerance of water pollution and a desire to have the plant closed. Forty-two percent of those surveyed were willing to close the plant, and these people were found to have unfavorable (disapproving) attitudes toward pollution, to discuss it more, and to have white collar occupations. Noticeably few young people were in favor of the closure. This, the authors theorized, was due to the fact that they were mostly short-time residents looking for work.

The public preferred economic growth to environmental protection in two studies (Milbrath, 1975; Winham, 1972), but the results were reversed in another (Milbrath, 1977). Growth was strongly favored by urban blacks, and protection was favored by rural people (Milbrath, 1977). Buttel (1978) found only a modest correlation between welfare-state liberalism and support for economic growth among his working-class respondents. From this he speculated (by implication) that environmentalists may be able to convince this group that economic growth is not a prerequisite to achieve their aspirations of wealth redistribution, thereby persuading them to shift their support to environmental protection. Interestingly, many leaders saw no need for an environment/growth trade-off (Milbrath, 1975). Winham (1972) found that those in favor of growth were less likely to see pollution as a problem and were not concerned about abatement costs. On a slightly different note, Murch's (1971) respondents felt that one way to protect the environment was not to bring in any polluting industry.

REFERENCES

Albrecht, S.L. "Environmental Social Movements and Counter-Movements: An Overview and an Illustration." Journal of Voluntary Action Research, 1(October):2-11, 1972.

Albrecht, S.L. "The Environment as a Social Problem." In: Social Problems as Social Movements, A.L. Mauss, ed. J.B. Lippincott Company, New York, New York, 1975. pp. 556-605.

Althoff, P., W.H. Greig, and F. Stuckey. "Environmental Pollution Control Attitudes of Media Managers in Kansas." Journalism Quarterly, 50(4): 666-672, 1973.

Auld, D.A.L. "Willingness to Pay for Pollution Abatement: A Case Study." Alternatives, 3(1):34-36, 1974.

Brunner, J.A., P. Gravengaard, and G. Bennett. Pollution in the Local Community: Citizen Attitudes and Willingness to Make Personal Sacrifices in Abatement. Occasional Paper No. 23. Business Research Center, College of Business Administration, The University of Toledo, Toledo, Ohio, 1973. 50 pp.

Buttel, F.H. "Economic Growth and the Welfare State: Implications for the Future of Environmentalism." Social Science Quarterly, 58(4):692-699, 1978.

Carlson, K.T. "The People's Lake." Environment, 17(2):16-20,25,26, 1975.

Carter, S., M. Frost, C. Rubin, and L. Sumek. Environmental Management and Local Government. EPA-600/5-73-016, U.S. Environmental Protection Agency, 1974. 390 pp. [NTIS: PB232955]

Costantini, E., and K. Hanf. "Environmental Concern and Lake Tahoe: A Study of Elite Perceptions, Backgrounds, and Attitudes." Environment and Behavior, 4(2):209-242, 1972.

Diamond, R.S. "What Business Thinks. The Fortune 500-Yankelovich Survey." Fortune, 81(2):118,119,171,172, 1970.

Dillman, D.A., and J.A. Christenson. "The Public Value for Pollution Control." In: Social Behavior, Natural Resources, and the Environment, W.R. Burch, N.H. Cheek, Jr., and L. Taylor, eds. Harper and Row, Publishers, New York, New York, 1972. pp. 237-256.

Dillman, D.A., and J.A. Christenson. "The Public Value for Air Pollution Control: A Needed Change of Emphasis in Opinion Studies." Cornell Journal of Social Relations, 10(1):73-95, 1975.

Donohue, G.A., C.N. Olien, and P.J.Tichenor. "Communities, Pollution, and Fight for Survival." Journal of Environmental Education, 6(1):29-37, 1974.

Downs, A. "Up and Down with Ecology--The 'Issue-Attention Cycle.'" The Public Interest, No. 28:38-50, 1972.

Draper, D. Public Participation in Environmental Decision Making. Exchange Bibliography #396, Council of Planning Librarians, Monticello, Illinois, 1973. 28 pp.

Dubos, R. "Promises and Hazards of Man's Adaptability." In: Environmental Quality in a Growing Economy, H. Jarrett, ed. The Johns Hopkins Press, Baltimore, Maryland, 1966. pp. 23-39.

Dunlap, R.E. "The Impact of Political Orientation on Environmental Attitudes and Actions." Environment and Behavior, 7(4):428-454, 1975.

Dunlap, R.E., and R.P. Gale. "Party Membership and Environmental Politics: A Legislative Roll Call Analysis." Social Science Quarterly, 55(December): 4, 1974.

Dunlap, R.E., and R.P. Gale. "Politics and Ecology: A Political Profile of Student Eco-Activists." Youth and Society, 3(June):379-397, 1972.

Dunlap, R.E., and R.B. Hefferman. "Outdoor Recreation and Environmental Concern: An Empirical Examination." Rural Sociology, 40(1):18-30, 1975.

Eastman, C., A. Randall, and P.L. Hoffer. "How Much to Abate Pollution?" *Public Opinion Quarterly*, 38(4):574-584, 1974/75.

Erskine, H. "The Polls: Pollution and Industry." *Public Opinion Quarterly*, 36(2):263-280, 1972a.

Erskine, H. "The Polls: Pollution and its Costs." *Public Opinion Quarterly*, 36(1):120-135, 1972b.

Faich, R.G., and R.P. Gale. "The Environmental Movement: From Recreation to Politics." *Pacific Sociological Review*, 14(July):270-287, 1971.

Franz, R.E., Jr. *Public Behavior and Attitudes in Response to Reported Hazardous Drinking Water - A Feasibility Study*. EPA-600/1-76-026, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1976. 55 pp. [NTIS: PB257981]

Fry, F.L., and R.J. Hock. "Who Claims Corporate Responsibility? The Biggest and the Worst." *Business and Society Review*, No. 18:62-65, 1976.

Gale, R.P. "From Sit-In to Hike-In: A Comparison of the Civil Rights and Environmental Movements." In: *Social Behavior, Natural Resources, and the Environment*, W.R. Burch, N.H. Cheek, Jr., and L. Taylor, eds. Harper and Row, Publishers, New York, New York, 1972. pp. 280-305.

Goldman, C.R. "Environmental Impact and Water Development." In: *Environmental Quality and Water Development*, C.R. Goldman, J. McEvoy, III, and P.J. Richerson, eds. W.H. Freeman and Company, San Francisco, California, 1973. pp. 1-11.

Groves, D.L., and H. Kahalas. "Values: Assimilation and Accommodation." *Cornell Journal of Social Relations*, 10(1):111-137, 1975.

Heberlein, T.A. "The Land Ethic Realized: Some Social Psychological Explanations for Changing Environmental Attitudes." *Journal of Social Issues*, 28(4):79-87, 1972.

Jensen, B.T., and J.M. Stormes. *A Psychometric Study of Attitude Factors and Problems of Solid Waste*. Contract No. CPE 69-107, U.S. Environmental Protection Agency, 1971.

Joseph M. Viladas Company. *The American People and Their Environment-1973. A Study of National Opinion and Attitudes About Environmental Problems and Their Solution for the United States Environmental Protection Agency, Volume I*. OPA-EPA 68-01-0905, U.S. Environmental Protection Agency, Washington, D.C., 1973. [NTIS: PB227020]

Klee, A.J. "Attitude Concepts and Applications to Solid Waste Management." U.S. Environmental Protection Agency, Cincinnati, Ohio, 1973. 39 pp. (Also see Klee, A.J. "Aspects of Sampling Attitudes Towards Solid Waste Problems." In: *Statistical and Mathematical Aspects of Pollution Problems*, J.W. Pratt, ed. Marcel Dekker, Inc., New York, New York, 1974. pp. 315-327.)

Koenig, D.J. "Additional Research on Environmental Activism." *Environment and Behavior*, 7(4):472-485, 1975.

Lackey, L.L., T.O. Jacobs, and S.R. Stewart. *Public Attitudes Toward Hazardous Waste Disposal Facilities*. EPA-670/2-73-086, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1973. 195 pp. [NTIS: PB223638]

Langowski, A., and J. Sigler. *Citizen Attitudes Toward the Environment: An Appraisal of the Research*. IIEQ-40.004, Illinois Institute for Environmental Quality, Chicago, Illinois, 1971. 69 pp. [NTIS: PB214190]

LaPorte, T.R., and D. Metlay. "Technology Observed: Attitudes of a Wary Public." *Science*, 188(4184):121-127, 1975.

Levenson, H. "Ecological Knowledge and Perception of Environmental Modifiability." *American Psychologist*, 29(4):274-275, 1974.

Louis Harris and Associates, Inc. *A Second Survey of Public and Leadership Attitudes Toward Nuclear Power Development in the United States*. A study conducted for Ebasco Services Incorporated, New York, New York, November 1976.

Lowenthal, D. "Assumptions Behind the Public Attitudes." In: *Environmental Quality in a Growing Economy*, H. Jarrett, ed. The Johns Hopkins Press, Baltimore, Maryland, 1966. pp. 128-137.

Ludwig, J.H., G.B. Morgan, and T.B. McMullen. "Trends in Urban Air Quality." *Transactions, American Geophysical Union*, 51(May):468-475, 1970.

Mackay, B.B., Jr. "Chemical Wastes Snafu Spurs State Planning." *Solid Wastes Management*, 19(7):40,68, 1976.

Maderthaner, R., P. Pahner, G. Guttmann, and H.J. Otway. *Perception of Technological Risks: The Effect of Confrontation*. RM-76-53, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976. 24 pp.

Maloney, J.C., and L. Slovonsky. "The Pollution Issue: A Survey of Editorial Judgments." In: *The Politics of Ecosuicide*, L.L. Roos, Jr., ed. Holt, Rinehart and Winston, Inc., New York, New York, 1971. pp. 64-78.

McEvoy, J., III. "The American Public's Concern With the Environment." In: *Environmental Quality and Water Development*, C.R. Goldman, J. McEvoy, III, and P.J. Richerson, eds. W.H. Freeman and Company, San Francisco, California, 1973. pp. 135-156.

EPA-287 (Cin.)
(4-76)

Means, R.L. "Public Opinion and Planned Changes in Social Behavior: The Ecological Crisis." In: Social Behavior, Natural Resources, and the Environment, W.R. Burch, N.H. Cheek, Jr., and L. Taylor, eds. Harper and Row, Publishers, New York, New York, 1972. pp. 203-213.

Milbrath, L.W. Environmental Beliefs: A Tale of Two Counties. Social Science Research Institute and Social Science Measurement Center, State University of New York, Buffalo, New York, 1975. 136 pp.

Milbrath, L.W. An Extra Dimension of Representation in Water Quality Planning: A Survey Study of Erie and Niagara Counties, New York, 1976. Environmental Studies Center, State University of New York, Buffalo, New York, 1977. 50 pp.

Miller, D. "The Allocation of Priorities to Urban and Environmental Problems by Powerful Leaders and Organizations." In: Social Behavior, Natural Resources, and the Environment, W.R. Burch, N.H. Cheek, Jr., and L. Taylor, eds. Harper and Row, Publishers, New York, New York, 1972. pp. 306-331.

Mitchell, R.C. "Environment: An Enduring Concern." Resources, No. 57:1-2, 20-21, 1978.

Morrison, D.E. "The Environmental Movement: Conflict Dynamics." Journal of Voluntary Action Research, 2(Spring):74-85, 1973.

Morrison, D.E., K.E. Hornback, and W.K. Warner. "The Environmental Movement: Some Preliminary Observations and Predictions." In: Social Behavior, Natural Resources, and the Environment, W.R. Burch, N.H. Cheek, Jr., and L. Taylor, eds. Harper and Row, Publishers, New York, New York, 1972. pp. 259-279.

Munton, D., and L. Brady. American Public Opinion and Environmental Pollution. The Behavioral Science Laboratory Research Report, University of Ohio, 1970.

Murch, A.W. "Public Concern for Environmental Pollution." Public Opinion Quarterly, 35(1):100-106, 1971.

National Analysts, Inc. Metropolitan Housewives' Attitudes Toward Solid Waste Disposal. EPA-R5-72-003, U.S. Environmental Protection Agency, Washington, D.C., 1972. 90 pp.

O'Riordan, T. "Public Opinion and Environmental Quality: A Reappraisal." Environment and Behavior, 3(2):191-214, 1971a.

O'Riordan, T. "Towards a Strategy of Public Involvement." In: Perceptions and Attitudes in Resources Management, W.R.D. Sewell and I. Burton, eds. Information Canada, Ottawa, Canada, 1971b. pp. 99-110.

Orr, R.H. "The Additive and Interactive Effects of Powerlessness and Anomie in Predicting Opposition to Pollution Control." Rural Sociology, 39(4): 471-486, 1974.

Otway, H.J., and M. Fishbein. *The Determinants of Attitude Formation: An Application to Nuclear Power*. RM-76-80, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976. 31 pp.

Pahner, P.D. *A Psychological Perspective of the Nuclear Energy Controversy*. RM-76-67, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976. 27 pp.

Rappeport, M., and P. Labaw. *Public Attitudes and Behavior Regarding Energy Conservation: Detailed Tabulations by U.S. Population and Population Segments. Waves 28 and 29*. FEA/D-76/252, Federal Energy Administration, Washington, D.C., 1975. 42 pp. [NTIS: PB254592]

Russell, C. *The Evolution of the Nature Magazine: A Case Study of Three Publications: Outdoor America, National Audubon, American Forests, 1954-1969*. M.A. Thesis, University of Michigan, Ann Arbor, Michigan, 1970.

Salcedo, R.N., H. Read, J.F. Evans, and A.C. Kong. "Rural-Urban Perspectives of the Pesticide Industry." *Rural Sociology*, 36(4):554-562, 1971.

Schnaiberg, A. "Politics, Participation and Pollution: The 'Environmental Movement.'" Mimeographed, Northwestern University, 1971.

Sewell, W.R.D., and H.D. Foster. "Environmental Revival: Promise and Performance." *Environment and Behavior*, 3(2):123-134, 1971.

Sharma, N.C., J.E. Kivlin, and F.C. Fliegel. "Environmental Pollution: Is There Enough Public Concern to Lead to Action?" *Environment and Behavior*, 7(4):455-471, 1975.

Sigler, J. *Attitudes of Illinois Citizens Toward Solid Waste and the Environment*. IIEQ-73-6, Illinois Institute for Environmental Quality, Chicago, Illinois, 1973. 140 pp. [NTIS: PB223457]

Slovic, P., and B. Fischhoff. "How Safe is Safe Enough? Determinants of Perceived and Acceptable Risk." Draft chapter in: *The Management of Nuclear Wastes*, L. Gould and C.A. Walker, eds. Yale University Press (no date). 39 pp.

Smith, W.J.J. *Environmental Policy and Impact Analysis: Origins, Evolution, and Implications for Government, Business, and the Courts*. The Conference Board, Inc., New York, New York, 1973.

Sofranko, A.J., and W.M. Bridgeland. "Agreement and Disagreement on Environmental Issues Among Community Leaders." *Cornell Journal of Social Relations*, 10(1):151-162, 1975.

Swan, J.A. "Psychological Response to the Environment." In: *Environmental Quality and Water Development*, C.R. Goldman, J. McEvoy, III and P.J. Richerson, eds. W.H. Freeman and Company, San Francisco, California, 1973. pp. 95-110.

EPA-287 (Cin.)
(4-76)

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Taviss, I. "A Survey of Popular Attitudes Toward Technology." *Technology and Culture*, 13(4):606-621, 1972.

Tognacci, L.N., R.H. Weigel, M.F. Wideen, and D.T.A. Vernon. "Environmental Quality: How Universal is Public Concern." *Environment and Behavior*, 4(2):73-86, 1972.

Tremblay, K.R., and R.E. Dunlap. "Rural-Urban Residence and Concern with Environmental Quality: A Replication and Extension." *Rural Sociology*, 43(3):474-491, 1978.

Trigg, L.J., D. Perlman, R.P. Perry, and M.P. Janisse. "Anti-Pollution Behavior: A Function of Perceived Outcome and Locus of Control." *Environment and Behavior*, 8(2):307-313, 1976.

Trop, C., and L.L. Roos, Jr. "Public Opinion and the Environment." In: *The Politics of Ecosuicide*, L.L. Roos, Jr., ed. Holt, Rinehart and Winston, Inc., New York, New York, 1971. pp. 52-63.

White, G.F. "Formation and Role of Public Attitudes." In: *Environmental Quality in a Growing Economy*, H. Jarrett, ed. The Johns Hopkins Press, Baltimore, Maryland, 1966. pp. 105-127.

Winham, G. "Attitudes on Pollution and Growth in Hamilton, or 'There's an Awful Lot of Talk These Days About Ecology.'" *Canadian Journal of Political Science*, 5(3):389-401, 1972.

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APPENDIX E

FACTORS INFLUENCING DISCOUNT RATES FOR ENVIRONMENTAL PROJECTS

INTRODUCTION

This appendix discusses the selection of a discount rate for public projects, presenting the arguments for and against the use of a social discount rate that is lower than the rate of discount used to assess private sector projects. The discussion also addresses the question of whether or not the discount rate used on social projects should be raised to reflect risk. (In this context, i.e., capital markets, the term "risk" is used to denote any uncertainty.)

Where a project can have irreversible effects that extend beyond one generation, the choice of a discount rate becomes more complex, and the whole concept of discounting has been questioned. This appendix discusses these issues and develops a pragmatic solution to the problem.

THE SOCIAL DISCOUNT RATE

If for the moment one disregards the question of risk and considers risk-free projects, there are two principal opposing views on the use of a social discount rate that is lower than the business rate. On one hand, it is argued that private market decisions generally favor the short term and do not make sufficient provision for the future, leading to a rate of consumption that is too high (Krutilla and Fisher, 1975). Hence a lower or "social" discount rate is proposed in order to adjust private preferences for consumption versus investment or conservation (as expressed in the private discount rate) to a time preference that is deemed appropriate for society as a whole (Marglin, 1963). The requirement for a lower discount rate to stimulate social projects (as opposed to private projects) stems from the long time scales over which some social projects operate (e.g., water resource developments) and the pattern of expenditures and benefits (which are equivalent to income). This pattern usually involves heavy expenditures in the early years of a project with benefits, usually small in the early years, that continue for a long time.

Another argument for a low social interest rate relates to positive externalities. Therefore, capital put to public use often has a higher social rate of return than the same capital put to private use. Hence it is claimed that a lower discount rate is needed to stimulate social projects (U.S. Congress, Senate, 1974; Musgrave and Musgrave, 1976). Clearly, the

PAGE NUMBER
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extent of any externalities depends on where the boundary for evaluation of the project is drawn. However, as Arrow and Kurz (1970) point out, the benefits of cleaner water, for example, may be so widely dispersed that it would be impracticable to devise a way of charging for these benefits, and correspondingly it would probably be difficult to value the benefits.

On the other hand, it is argued that the correct discount rate is the opportunity cost of capital based on the returns when the project resources are put to alternative uses. Thus it is claimed that to use a low social rate of discount on public projects will divert capital from the private sector to the public sector, leading to a distribution of investment that is not optimally efficient (Musgrave and Musgrave, 1976). In a real world situation, further complications are introduced by the distorting effects of corporate income taxes. Some authors consider that the appropriate social discount rate is the before-tax return in the private sector (Baumol, 1968). However, others argue that the relevant discount rate for use on social projects could be either the before-tax or the after-tax private sector return, depending on whether the funds are diverted from investment or consumption (Musgrave and Musgrave, 1976). In addition, there are a number of ways of adjusting the investment criteria when social and private discount rates diverge. Discussion of these topics is beyond the scope of this appendix, and the reader is referred to the literature (see Herfindahl and Kneese, 1974; Mishan, 1971; Dasgupta, Sen, and Marglin, 1972; Krutilla and Fisher, 1975).

ADJUSTMENT OF THE DISCOUNT RATE FOR RISK

In assessing business projects, it is a common practice to raise the discount rate (or the minimum acceptable rate of return) in order to allow for uncertainty associated with the project. Uncertainty can arise from numerous factors such as the magnitudes of the expenditures and revenues, the timing and duration of the phases of the project as well as the possibility of "catastrophic" events--a major uninsured accident, for example. Correspondingly, it is assumed that an investor will demand a higher rate of return (expressed as an expected value) from what is perceived to be a risky project than from a safe one. Thus investment criteria will reflect the investor's risk aversion by including a risk premium in the discount rate.

Similar arguments can be applied to public projects, and some authors hold that public projects should be assessed in exactly the same way as private projects to avoid the capital diversion effect already mentioned. The alternative contention is that public investment criteria should not include a risk premium. Several arguments can lead to this position, including claims that the private capital markets are so imperfect that they give no useful information about the individual's risk preferences, and that many of the risks in the private sector (such as moral risks) do not exist in the public sector (Arrow and Lind, 1970). However, there are three major arguments for a risk-free approach. The first is that governments invest in a great number of diverse projects, which enable them to pool risks to a far greater extent than the individual investor (i.e., a government acts as its own insurer). Second, a government distributes the risk associated with any one project over such a wide range of individuals that the total cost of risk-bearing is insignificant. The third argument is that the state is more than a mere collection of individuals and has an existence and interests apart from its individual members; government policy therefore need not reflect the risk aversion of individual preferences (Arrow and Lind, 1970). Again, the reader is referred to the literature for more details of this debate (see Herfindahl and Kneese, 1974; Mishan, 1971; Dasgupta, Sen, and Marglin, 1972; Krutilla and Fisher, 1975).

INTERGENERATIONAL EFFECTS

The preceding discussion on the choice of a discount rate used arguments that are appropriate to the viewpoint of the present generation. However, where a longer time span is involved, society should also consider the viewpoint of future generations. This is particularly important for any projects that could or do result in (1) irreversible changes, such as modifications to the natural environment, or (2) the use or disposition of nonrenewable resources. Construction (e.g., of a dam or landfill) is irreversible when it causes environmental changes. Thus almost any effect that persists for more than one generation could be regarded as irreversible.

Two of the arguments already presented for a low social discount rate are particularly appropriate when intergenerational effects are considered. These are: (1) The view that society is more than a collection of individuals and hence does not have to be risk averse, and, more important (2) the view that market decisions stress present consumption to the detriment of conservation. (Page [1977] provides, in the context of resource conservation, an excellent and extensive discussion of the implications of the various approaches to the choice of a discount rate.) Though the second argument can be applied directly (in assessing the benefits of resource recovery), the general view that one generation should not unduly mortgage another's activities in return for immediate benefits is applicable to the management of any "nontreatable" waste.

Krutilla and Fisher (1975) have analyzed some intergenerational problems and conclude that where there is less than perfect altruism, the overall optimum use of a limited resource will not be achieved, because of the inability of different generations to bargain with each other. Consequently, each generation will optimize the use of resources from its own viewpoint, and each succeeding generation will wish to revise the plan to provide it with the maximum utility available from the remaining resources. Of particular interest is the case where an option demand (see Appendix C) increases with time, and a project that is justified (using the potential Pareto criterion) at $t=0$, may cease to be justified when evaluated at $t=t_1$ ($t_1>0$) as a result of the increasing benefits of maintaining the status quo. Furthermore, the magnitude of the benefits (viewed from $t=t_1$, or later) of not undertaking the project could be sufficient to permit the compensation of early beneficiaries of the project and still satisfy the potential Pareto criterion. Thus where an irreversible action is contemplated, some additional test of efficiency is required if society is to aspire to altruism. This test, attributed to Scitovsky, is discussed in Krutilla and Fisher (1975). (Anderson [1978] also provides a useful discussion, from the viewpoint of resource conservation, of intergenerational effects with more emphasis on distributional considerations.)

OBJECTIONS TO DISCOUNTING

In the above discussion, the concept of discounting was not an issue, although Krutilla and Fisher (1975) show (in the context of the consumption of a fixed resource stock) that to achieve altruism, the discount rate must be uniform between generations. However, several authors (concerned with empirical cost-benefit analyses) have questioned the concept of discounting on the grounds that it unreasonably penalizes future generations, or even the later welfare of the present generation. The problem is that with any conventional rate of discount, even a low social rate, the future is so heavily discounted that after a few decades, distant events can be disregarded in virtually every case. This is no great problem for a conventional project (such as the construction of an incinerator), where technological obsolescence is expected to limit the project's useful life by a couple of decades; but it can present difficulties where human life or the environment are involved.

This issue has been pointed up by a National Academy of Sciences committee as follows:

> There have been long-standing debates as to the appropriateness of applying a discount rate to effects on future generations, since any positive rate of discount will directly discriminate in favor of choices that involve bad impacts on later generations but not on earlier ones. Again by way of example, if the discount rate were 5 percent, 100 cases of toxic poisoning 75 years from now would be equivalent to about 3 cases today; or 1 case today would be valued the same as 1,730 cases occurring in 200 years, or the same as the current world population (more than 3 billion cases) in 450 years. Clearly, intergenerational effects of these magnitudes are ethically unacceptable; yet they might be made to appear acceptable if the traditional social rate of discount concept were used to discount future costs to compare with present benefits. Some other method of ethically weighting intergenerational incidence of effects must be devised.
> (National Academy of Sciences, 1975:177)

The committee also noted that there is as yet no generally accepted method for weighting the intergenerational incidence of benefits and costs.

Another National Academy of Sciences (1977) committee also indicated that it had problems with discounting with respect to the valuation of lives exposed to radiation and proposed that:

> Weighting factors should be applied to those terms which may be undervalued by market place economics. Typically, these are likely to include the terms which have a component which involves people not able to take part in the decision-making process. The values of the weighting factors have to be established by society in general, whether through the political process, public survey, or other means. (National Academy of Sciences, 1977:69,70)

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Sociologists have, however, developed some alternatives to the utility approach inherent in discounting. Thus if the present generation desires to minimize the regret of future generations as to the present generation's choices, then the appropriate social rate of discount is zero--i.e., all generations are valued equally over a finite planning horizon (Schulze, 1974). Rawls (1971) argues that society should focus attention on maximizing the welfare of the poorest individual. This approach has been developed by Solow (1974) and Phelps and Riley (1978), but their arguments concentrate on the consumption of nonrenewable resources, and although they are interesting, they cannot be applied directly to hazardous waste management problems (also see Page, 1977). Epp et al. (1977) suggest the use of a zero discount rate for cost-benefit analysis of pesticide use, although they do not justify the proposal.

APPLICATION TO HAZARDOUS WASTE MANAGEMENT

General

The use of discounting in empirical studies involving intergenerational effects is clearly problematical. However, in a mixed economy, the complete abandonment of the discounting concept for public decisions could call for some difficult and perhaps unsatisfactory second best analysis,* as discounting is implicit in virtually all business decisions. Discounting is clearly not a topic upon which wide agreement will readily be reached, yet some solution must be adopted to proceed with any numerate analysis. The author will therefore offer some pragmatic suggestions and arguments that could be appropriate to the particular characteristics of "nontreatable" hazardous wastes. Note that many decisions relating to treatable wastes are reversible (assuming that costs sunk in physical facilities are disregarded) and only involve a conventional time scale as opposed to an intergenerational one. Hence in these cases, the only problem is the choice between a social and a market discount rate.

Intergenerational Discounting

Where intergenerational effects are possible (e.g., effects that stem from environmental threats), two approaches could be employed: (1) not to discount the effects of threats, or (2) not to further discount the effects of any threats that occur after one generation. In the second approach, the intention is that all costs and impacts that occur during a normal (single generation) project life are discounted in the usual way, but that no effect is further discounted if it occurs past this time. Both approaches have the added practical attraction that they eliminate or reduce the problems associated with deciding upon the time at which a threat is assumed to materialize. It is difficult to predict the time at which a threat that arises from hazardous waste disposal (as opposed to treatment, etc.) might become a reality. It is true, for example, that given sufficient

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* If the social and business discount rates diverge, then this will cause deviations from Pareto optional conditions (see Section 5) with the result that any optimum reached will be what economists refer to as a "second best" condition.

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precipitation and geohydrologic data, the emergence and movement of a leachate from some form of land disposal could be predicted. In practice, however, adequate data are not likely to be available--and the greatest threats may come from unanticipated sources such as an unrecognized interconnection between two aquifers. Effects may be cumulative and may not become apparent until some (probably ill-defined) threshold level is passed. Where the threat relates to an irregular or random process (such as an uncommon natural event), the timing cannot be predicted, although of course it might be possible to derive an expected value. Hence use of the methodology is simplified if threat timing does not affect the results.

Rationale for Not Discounting

While neither of the two approaches suggested above can be rigorously justified (unless one accepts the minimum regret criterion mentioned earlier), arguments in their favor can be put forward. First, little is known about man's future uses of the environment, and especially those to which it may be put after two or three decades (i.e., one generation later). Society may need to employ some resources that are currently unused and little valued. For example: When might we need to extract either freshwater or minerals from a saline aquifer? When may we need and be ready to farm the ocean? When may we need to use the land where a landfill is presently located? An allowance for the unknowns can be made by placing some form of option value on them, and it is not unreasonable to suggest that its value increases with time. This increase would stem from the increasing relative scarcity of the fixed supply of environmental resources in comparison to man's growing real wealth. Thus the further into the future that one looks, the higher are likely to be the opportunity costs associated with irreversible decisions. Put another way, the materialization of a threat (such as contamination of an aquifer that might be the only low-cost water supply available to meet future increased demand) may prove to be increasingly costly as one moves further into the future (and alternative water sources are put to other uses, raising the cost of the next feasible supply).

The increasing opportunity cost hypothesized above could be regarded as balancing the discounting effect, leading to an argument for not discounting when the impacts of these threats are expressed in today's values. The drawback to this argument is that there is no particular reason why the discount rate should become zero, i.e., that the two effects should exactly balance. The appropriate rate (i.e., that which would be determined with hindsight after the events have occurred) might turn out to be a low positive rate, zero, or even a negative discount rate (i.e., a growth rate). But this information is not available, and a zero rate has the attraction of simplicity.

Rationale for Discounting Over One Generation Only

The concept of discounting over a "normal" project life, but thereafter holding the discount factor constant (i.e., not continuing to discount) has an even stronger pragmatic attraction. The lives of many industrial projects are limited by technological obsolescence, either directly via the process technology used, or indirectly through changes in the marketplace.

Consequently, industrial project lives are usually taken as one and a half, two, or at the most three decades.* Technologies pass through a succession of phases as they move from basic research or concept development to commercial use. Technologies that are likely to be used in the next decade or so will generally be well advanced along this progression and hence comparatively easy to identify. By contrast, some of the technologies that will be important after three decades, for example, may not yet be conceived, or they may be in the very early stages of development making technological predictions over this time scale most uncertain (Taylor, 1978).

Thus it can be argued that current valuations of resources will probably reflect their utility over the next decade or so with reasonable accuracy, but that beyond this period, uncertainty becomes so great that some resources could be seriously undervalued. (Correspondingly, some resources currently in use may be of little value by that time.) Discounting during the first generation (say 20 or 30 years, which is about the same duration as a normal project life) but not continuing to discount environmental effects thereafter is equivalent to postulating an impact or opportunity cost that starts to rise when the period of high uncertainty is reached at the end of the conventional project life. A major attraction of the approach, however, is that it simulates the normal industrial decisionmaking procedures (which in most cases do not consider times beyond one generation), yet it does not overly discount the very distant future.

Conclusion

These two proposed alternative approaches for handling intergenerational effects will lead to present values for these effects or threats that differ by up to one order of magnitude. (For example, by ratios of 3.4:1, and 10.8:1 for discount rates of 5 and 10 percent respectively, over a period of 25 years.) Since estimates of the magnitudes (and, if used, of the probabilities) of environmental threats are likely only to be order-of-magnitude estimates, the difference need not be of great concern. The author finds the arguments for the second approach (i.e., discounting during the first generation, but not thereafter) particularly appealing, but the first approach (not discounting at all) has the advantage of simplicity.

Both approaches could be difficult to apply in some circumstances. If the period of evaluation is infinite, any cost that continues for an indefinite period will have an infinite present value, unless discounting is employed. This presents no problem where a lump-sum valuation of an effect is possible (e.g., a one-shot valuation of some damage, such as a cleanup or replacement cost); but where some continuing cost is involved (such as the maintenance cost for perpetual care, or a loss of existence value), the evaluation or planning horizon would have to be limited if discounting were not used.

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* Of course, it is also true that at the high rates of discount commonly used to evaluate industrial projects, the contribution to net present value made by any cash flow beyond this point is often very limited. This reduces the importance of accurately predicting the technological life of a project.

EPA-287 (Cin.)
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REFERENCES

Anderson, R.C. Evaluation of Economic Benefits of Resource Conservation Through Recycling. EPA-600/5-78-015, U.S. Environmental Protection Agency, Cincinnati, Ohio, 1978. 51 pp.

Arrow, K.J., and M. Kurz. Public Investment, The Rate of Return, and Optimal Fiscal Policy. The Johns Hopkins Press, Baltimore, Maryland, 1970. 246 pp.

Arrow, K.J., and R.C. Lind. "Uncertainty and the Evaluation of Public Investment Decisions." American Economic Review, 60(3):364-368, 1970.

Baumol, W.J. "On the Social Rate of Discount." American Economic Review, 58(4):788-802, 1968.

Dasgupta, P., A. Sen, and S. Marglin. Guidelines for Project Evaluation. United Nations, New York, New York, 1972. 399 pp.

Epp, D.J., F.R. Tellefsen, G.A. Shute, R.M. Bear, and K.P. Wilkinson. Identification and Specification of Inputs for Benefit-Cost Modeling of Pesticide Use. EPA-600/5-77-012, U.S. Environmental Protection Agency, Washington, D.C., 1977. 154 pp.

Herfindahl, O.C., and A.V. Kneese. Economic Theory of Natural Resources. Charles E. Merrill Publishing Company, Columbus, Ohio, 1974. 415 pp.

Krutilla, J.V., and A.C. Fisher. The Economics of Natural Environments: Studies in the Valuation of Commodity and Amenity Resources. The Johns Hopkins University Press, Baltimore, Maryland, 1975. 214 pp.

Marglin, S.A. "The Social Rate of Discount and the Optimal Rate of Investment." Quarterly Journal of Economics, 77(1):95-111, 1963.

Mishan, E.J. Cost-Benefit Analysis: An Introduction. Praeger Publishers, New York, New York, 1971. 374 pp.

Musgrave, R.A., and P.B. Musgrave. Public Finance in Theory and Practice. McGraw-Hill Book Company, New York, New York, 1976. 796 pp.

National Academy of Sciences. Decision Making for Regulating Chemicals in the Environment. National Academy of Sciences, Washington, D.C., 1975. 242 pp.

National Academy of Sciences. Considerations of Health Benefit-Cost Analysis for Activities Involving Ionizing Radiation Exposure and Alternatives. EPA 520/4-77-003, U.S. Environmental Protection Agency, Washington, D.C., 1977. 199 pp.

Page, T. Conservation and Economic Efficiency: An Approach to Materials Policy. The Johns Hopkins University Press, Baltimore, Maryland, 1977. 286 pp.

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Phelps, E.S., and J.G. Riley. "Rawlsian Growth: Dynamic Programming of Capital and Wealth for Intergeneration 'Maximin' Justice." Review of Economic Studies, 45(139):103-120, 1978.

Rawls, J. A Theory of Justice. The Belknap Press, Harvard University Press, Cambridge, Massachusetts, 1971. 600 pp.

Schulze, W. "Social Welfare Functions for the Future." American Economist, 18(1):70-81, 1974.

Solow, R.M. "Intergenerational Equity and Exhaustible Resources." Review of Economic Studies, Symposium on the Economics of Exhaustible Resources, 1974. pp. 29-45.

Taylor, G.C. Methodologies for Characterizing Technologies. EA-320, The Electric Power Research Institute, Palo Alto, California, 1978. 138 pp.

U.S. Congress, Senate. Evaluation of Techniques for Cost-Benefit Analysis of Water Pollution Control Programs and Policies, Document No. 93-132. U.S. Government Printing Office, Washington, D.C., 1974.

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APPENDIX F

RISK AND DECISIONMAKING

Considerations of risk appear in several places in this study. The purpose of this appendix is to interrelate the various aspects of risk, to provide limited further information about some of these aspects, and to provide the interested reader with an entry to the wealth of risk-related literature that may be relevant to decisionmaking about hazardous wastes.

ASPECTS OF RISK

The term "risk" has different implications to different people. Rowe, in a broad discussion of many aspects of risk, defines risk as

> . . . the potential for realization of unwanted negative consequences of an event or combination of events to individual groups of people or to physical and biological systems.
> (Rowe, 1975:1)

Risk only becomes relevant when it affects decisionmaking, and all decisionmaking involves some element of risk, even if the potential negative consequences of a decision are as simple as failing to maximize utility or satisfaction in a choice between two competing products. However, risk does not play a significant role in every decision, and hence only a limited proportion of decisions would be perceived by a decisionmaker as being risk related. It is possible to classify decisionmaking on the basis of whether the viewpoint used is predominantly personal, economic, or societal.

Risk taking in personal decisions might involve social behavior, such as the acceptability of drug taking to peer groups; or it might relate to an individual's well-being or safety, such as a decision to risk the consequences of swimming in polluted water. Note that risks are taken voluntarily as a result of personal decisions.

Many business decisions involve predominantly economic risks. The basic uncertainty need not be economic; it could, for example, be a question of the ability of the firm's management to adequately control a venture, or it may be that a project involves an unproven technology. However, to the business firm, the ultimate consequences of an unsatisfactory performance in these areas will be measured in economic terms. The upwards adjustment of a required rate of return to reflect the perceived riskiness of a project is one way in which decisionmakers allow for economic risks.

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Another important aspect of economic risk-taking is insurance decisions. Insurance spreads over many individuals the risk of adverse economic consequences from what is usually a comparatively unlikely event. The basis of insurance is that many individuals (or organizations) prefer to pay a premium (which is in excess of the expected value of the loss due to the transaction costs involved) rather than risk the chance of serious economic consequences should specified events occur. These events are usually those over which the insured has little or no control, for example, automobile accidents (little control) or natural disasters such as floods (no control). The fact that individuals will pay a premium to obtain insurance illustrates a widely observed phenomenon--that many people are risk averse, and prefer to minimize the potential for adverse consequences. However, individuals often exhibit risk proneness in some decisions; for example, research has shown that individuals frequently do not carry insurance against high-loss, low-probability events (discussed later in this appendix).

Where risks have the potential to affect large numbers of persons, they become societal risks. However, perhaps the most important aspect of societal risk is that the risks are largely incurred involuntarily. The distinction between voluntary and involuntary risks appears to be of practical as well as philosophical significance, as it appears that, for a given economic benefit, the public is willing to accept voluntary risks that are greater than involuntary risks (discussed later in this appendix).

Another key feature of societal risks is that individuals can make decisions that affect many others. In some cases these decisions are made by persons who (implicitly or explicitly) represent the public, but in others they are made by individuals in the light of their own specific interests. In the latter case, society often finds a way to constrain or control the decisions so that the public interest is not unduly damaged; for example, certain methods of disposing of hazardous waste might be prohibited by law as being too harmful to the environment.

There are many situations in which decisions are not purely personal, economic or societal; in some cases all three facets can be present. For example, if an individual decides to transport some obsolete and potentially dangerous explosives over the public highways, this could be viewed as a personal risk-taking decision. However, it also has societal implications via the risks to bystanders, and economic implications to the individual transporting the explosives, to his dependents, and to society (by way of road use costs, etc.).

Many risks have a technological element, even though the threat-initiating event may be natural. It may be that the technology itself is not completely reliable or understood (e.g., weather modification), that the man-technology combination is not secure (e.g., is a nuclear power station completely fail-safe?), or that technology is used to mitigate or minimize the effects of natural risks (e.g., design of buildings to resist earthquakes).

Many risk data for specific technologies, e.g., transport accident statistics, are readily available. Some of these that are applicable to hazardous waste management are presented in Appendix B on environmental

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threats. A problem sometimes encountered is the quantification of risk where historic data are unavailable or inadequate. One approach proposed to remedy this deficiency uses envelope curves to describe risk-consequence relationships (Kastenberg, McKone, and Okrent, 1976; Okrent and Whipple, 1977; Starr, 1972).

Recently there has been much research on the risks that complex technological systems pose to mankind, the preeminent example being electric power generation from nuclear or other fuels. (For example, see Okrent, 1975; Starr, Greenfield, and Hausknecht, 1972; Rasmussen, 1975; U.S. Atomic Energy Commission, 1974; Barrager, Judd, and North, 1976.) An associated development has been the growing use of technology assessments. While the objective of a technology assessment is to evaluate all the effects of the use of a technology, including direct costs and benefits, the emphasis is on long range consequences and side effects (National Academy of Engineering, 1972). Consequently, technology assessment is closely associated with risk evaluation. Technology assessments have been performed in such areas as precipitation augmentation (Weisbecker, 1974), transport of liquified natural gas and oil, and nuclear proliferation and safety (U.S. Congress, Office of Technology Assessment, 1977).

DECISIONMAKING UNDER UNCERTAINTY, AND RISK AVERSION

It is widely held that most individuals are risk averse. In the context of economics, this follows from the assumption that the marginal utility of wealth decreases as an individual's wealth increases, i.e., it is of the form shown in Figure F-1.

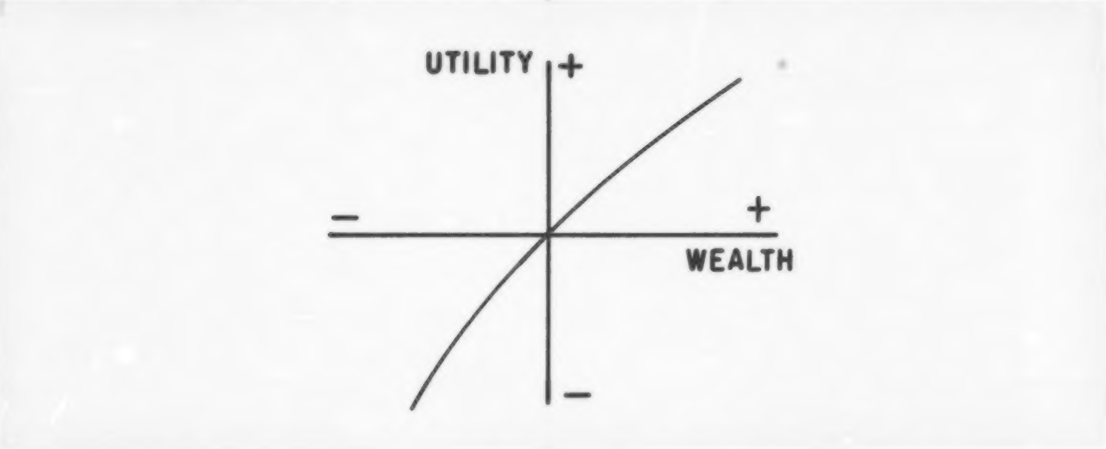

Figure F-1. Utility of wealth for a risk-averse individual.

(Source: Slovic et al., 1977:238.)

Consider a decisionmaker faced with a situation where he has a choice between (A) a certain $1 million payoff and (B) a probability p=0.5 of a $2 million payoff together with a p=0.5 of a zero payoff. If the decisionmaker is indifferent between choices (A) and (B), he is "risk neutral" since the

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expected value of choice (B) is $1 million, i.e., the same as (A). If he prefers (A) to (B), he is termed "risk averse"; however, should he prefer (B) to (A), he is considered "risk prone." Similar arguments apply to expenditures and losses of utility. A risk-averse decisionmaker might, for example, prefer to spend $1 million to avoid a potential waste problem rather than face a 90-percent probability of needing no expenditures together with a 10-percent probability of having to spend $10 million to contain the problem.

The above statements do not provide any information about the extent of the risk aversion (or risk preference) that a decisionmaker exhibits. This could be measured by determining the expected value of the uncertain situation at which the decisionmaker was indifferent between this and the certain outcome. To extend the waste containment example above, a decisionmaker who will spend $2 million to avert the specified risk is risk averse; a decisionmaker who will spend $3 million to avert the same risk is more risk averse. Maurer (1977) discusses ways of characterizing the extent of risk aversion and discusses some common empirical risk tolerance functions that can be used to quantify risk aversion.

Though individuals may exhibit risk-prone behavior in some situations, human behavior is generally characterized by risk aversion for monetary risks (Maurer, 1977). Consequently, some authors have suggested that where choices can be couched in purely economic terms, a specified degree of risk aversion can be built into the decisionmaking process (Okrent and Whipple, 1977). The concept includes the suggestion that we should be less risk averse in decisions concerning essential services (for example, in deciding to have a public electricity supply) than in peripheral services that are not particularly beneficial to society or where an almost equivalent function could be performed by alternative low-risk means (for example, substitutes for the use of PCB's in transformers).

The above discussion of risk aversion dealt with comparatively straightforward choices that are primarily economic in nature. Utility theory has traditionally been used to provide a theoretical basis for decisionmaking under uncertainty. It also facilitates the analysis of problems in which it is difficult to place a monetary value on some outcomes. (For example, see Von Neumann and Morgenstern, 1953; Ellsberg, 1961; Keeler and Zeckhauser, 1969; Fishburn, 1964, 1965; Raiffa, 1968; Fischer, 1975.)

Research on insurance and gambling decisions has developed empirical data about an individual's behavior when faced with a variety of uncertain situations, many of which are somewhat complex (Slovic, 1972a; Slovic and Lichtenstein, 1968; Slovic et al., 1977). If the individual is assumed to make logical decisions on the basis of utility, some of these findings can be surprising. For example, it appears that people are less inclined to insure against low-probability, high-loss events than high-probability, low-loss risks. This could be construed as implying risk-prone behavior, but an alternative explanation could be that there is a threshold level of probability for a damaging event below which individuals do not consider it worth carrying insurance (Slovic et al., 1977). Extending this result and drawing on other work, Slovic et al., conclude that when dealing with insurance against risks from natural hazards, there are many social and

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psychological factors that bear on an individual's decison (Slovic et al., 1977; Slovic, Kunreuther, and White, 1974; Kunreuther and Slovic, 1978).

Because utility theory alone is not entirely satisfactory for explaining observed behavior, an alternative psychology-based approach, now termed "bounded rationality," has been proposed (Simon, 1956, 1959). Bounded rationality postulates that individuals do not think probabilistically and that they try to avoid the necessity of directly facing uncertainty in decisionmaking (Slovic, Kunreuther, and White, 1974). It is assumed that an individual's cognitive limitations force him to construct a simplified model of the world, and that the decisionmaking goal becomes "satisficing" (i.e., finding an acceptable solution) rather than optimizing. There is empirical evidence that the way in which individuals process information is central to their decisionmaking procedures, which supports models of the bounded rationality type (Slovic, Kunreuther, and White, 1974; Slovic, 1972b; Tversky and Kahneman, 1974; Fischhoff, 1976).

It appears that there is a tendency for economic decisions made by groups to be more risky than by individuals, and that the risk-taking levels of some individuals increase following group discussion (Clark, 1971; Kogan and Wallach, 1967; also see Slovic, 1972b). This phenomenon has been called "risky shift." However, it is a complex subject, and groups will make less risky decisions under some circumstances (Cartwright, 1973).

RISK AND SOCIETY

One of the most difficult tasks with which a decisionmaker can be faced is the need to decide on a level of risk for society to bear. (A decisionmaker will have a personal risk aversion [related to the perceptions of others as to how well he has performed his job] that may not coincide with the level of risk aversion that is optimal for society. But this personal factor is disregarded in the following discussion.) The dilemma of choosing between comparative safety together with low cost-effectiveness versus greater risks but higher effectiveness--provided nothing goes wrong--has spawned article titles such as "How Safe is Safe Enough?"* (Fischhoff et al., 1976; Slovic and Fischhoff, in press), and "Balanced Risk: An Approach to Reconciling Man's Need with his Environment" (Wiggins, 1975). Ideally, one would like to be able to optimize the level of risk to which the public is exposed, but it is not an easy task to determine what the public really wants, the difficulty being greatly compounded by the "fuzziness" of the data (see Shinohara, 1976).

Otway and Pahner, who addressed risks in the context of technological systems, see risk on a series of levels:

1. Physical, biological risks to man and the environment;
2. The perception of these risks by individuals;

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* It appears that Starr (1969) was the first author to specifically pose the now well-known question "How Safe is Safe Enough?"

3. The potential risk to the psychological well-being of individuals based upon these perceptions;
4. The risks to social structures and cultural values as influenced by the collective psychological states of individuals.

(Otway and Pahner, 1976:123)

Otway uses the term "risk assessment" to describe the process of incorporating social values into risk-related, societal decisions (Otway, 1977; Otway and Pahner, 1976; Otway, 1975). Risk assessment is seen as consisting of two major components: Risk estimation and risk evaluation. Risk estimation involves identifying and quantifying the risks associated with a particular option; that is, it is the largely technical side of risk assessment. Some material on risk estimation has been presented in Appendix B. Risk evaluation involves determining the acceptability of these risks to society (Otway and Pahner, 1976; Slovic and Fischhoff, in press).

There are two principal approaches to risk evaluation (Fischhoff et al., 1976):

1. The revealed preference method;
2. The expressed preference method.

The basis of the revealed preference method is the assumption that through trial and error society has arrived at a satisfactory balance between the risks and benefits connected with any activity. Past economic risk and benefit data may therefore be used to reveal patterns of acceptable risk-benefit trade-offs. Acceptable risk for a new technology is considered to be that level of safety associated with ongoing activities having similar benefit to society (Fischhoff et al., 1976).

The "expressed preference" method, which has also been called the "controlled experiment" method (Otway and Pahner, 1976) and the "psychometric survey" (Fischhoff et al., 1976; Okrent and Whipple, 1977) depends on using a survey or questionnaire to find individual responses to risk or specific risk attributes (Okrent and Whipple, 1977).

Starr (1976, 1972, 1969) is the best known proponent of the revealed preference approach. He essentially compared risk of death with a valuation of the benefits received by the individual from the relevant activity. In most cases, benefits were valued by assuming that they were equal to the average expenditures by an individual on that activity. This analysis led Starr to the following conclusions:

> . . . (i) The indications are that the public is willing to accept 'voluntary' risks roughly 1000 times greater than 'involuntary' risks. (ii) The statistical risk of death from disease appears to be a psychological yardstick for establishing the level of acceptability of other risks. (iii) The acceptability of risk appears to be crudely proportional to the third power of the benefits (real or imagined). (iv) The social acceptance of risk is directly

> influenced by public awareness of the benefits of an activity, as determined by advertising, usefulness, and the number of people participating. . . . (Starr, 1969:1237)

The principal criticism of this approach is that the actual risk levels are not known to the public, and hence judgments will be based on perceived risks rather than actual risks.* The literature presents several other criticisms of the revealed preference approach, including the argument that the sociopolitical decisionmaking process does not reveal the true public preference for benefit-risk trade-offs, that revealed preferences do not differentiate between what is best and what is traditionally acceptable, and that they illustrate past values, not current ones (Okrent and Whipple, 1977; Linnerooth, 1975; Fischhoff et al., 1976). Also, Lave (1972) argues that Starr's distinction between voluntary and involuntary exposure is explained by the "public good" nature of the involuntary exposure situations. In a public situation, a large number of persons are exposed to the hazard, thereby reducing the acceptable per person risk in comparison with that for an individual activity.

In addition to the conceptual difficulties associated with the revealed preference approach, Starr's quantitative findings are also subject to doubt. Otway and Cohen (1975) have reanalyzed Starr's data, and show that the results are excessively sensitive to the assumptions made and to the way in which the data are handled. They conclude that simple mathematical relationships of the type suggested by Starr are unlikely (Otway and Cohen, 1975). In particular, Otway and Cohen did not replicate Starr's well known ratio of 1,000:1 for the required benefits from risks undertaken involuntarily as opposed to voluntarily. Some recent unpublished work has suggested that a 3:1 ratio may be more appropriate. (Personal communication, P. Slovic, Decision Research, Eugene, Oregon, September 5, 1978.)

The expressed preference approach has been the subject of investigation by workers at Decision Research (Fischhoff et al., 1976; Slovic and Fischhoff, in press; Slovic, 1978) and by Otway and others (Otway, 1975, 1977; Otway and Pahner, 1976). However, this approach has not, as yet, been widely applied. The principal disadvantage is that it measures attitudes, not behavior, and that it is difficult to project attitudes to behavior (Otway and Pahner, 1976; Okrent and Whipple, 1977).

In one particularly interesting study, Fischhoff et al. (1976) examined the way in which, for a given level of benefit, risk attributes affected the acceptability of a risk. Although this study was restricted to a small sample of members of the League of Women Voters and their spouses in Eugene, Oregon, it confirmed Starr's general finding that risks undertaken voluntarily were more acceptable than nonvoluntary ones; it also found that the acceptability of risk increased where the risk was controllable, familiar, known, and had immediate consequences. These results are illustrated in Figure F-2 and have the effect of favoring low-technology activities over high-technology activities (Fischhoff et al., 1976). In addition, the degree to which an activity's risk was potentially catastrophic, dread, and likely to be fatal also negatively influenced acceptability (Slovic, 1978).

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* This criticism is supported by work that illustrates that public judgment on the relative mortality risk from various causes (diseases, accidents, etc.) is far from accurate (Lichtenstein et al., 1978; Slovic, Fischhoff, and Lichtenstein, 1976). The biases in the responses were attributed to disproportionate exposure to the various causes (due to variation in coverage by the news media) and also to differences in memorability or imaginability of various events (Lichtenstein et al., 1978; Slovic and Fischhoff, in press).

Although the expressed preference approach reflects the public's views, it has already been shown that these views are liable to be colored by inaccurate ideas on the magnitude of risks, etc. One way to correct for this would be to provide appropriate, accurate data to the respondents. Slovic and Fischhoff (in press) provide a useful listing of the factors that can cause both erroneous views and erroneous analysis in dealing with risk estimates.

The two methods discussed above provide, in theory, means for determining optimum levels of risks acceptable to society. A method that involves aspects of both has been advocated by Rowe (1977), who proposed that for any given activity the risk levels inferred from historical data must be adjusted according to the degree of the inequity caused by a specific action (i.e., risks to those individuals who do not share the benefits) and the ability to control each risk. Rowe suggested that greater inequity and less control should dictate lower permissible risks.

Another method of determining risk acceptability is to argue that a risk that is reduced to well below the noise level should not be of significance. Thus if a risk is far smaller than that posed by natural, unavoidable hazards, it is claimed that it should be acceptably low* (Otway, 1975, 1977). A variety of historic data have been collected on various risks that can be used for this approach, many of which are included in the materials cited above. In addition, Baldewicz et al. (1974) provide a fairly comprehensive listing, and Tonnessen and Cohen (1977) provide data on naturally occurring hazardous materials in deep geologic formations as perspective for the relative hazard of burial of nuclear wastes. The disadvantage of this "comparative" approach is that the public may not perceive the relevant risk to be insignificantly low, and further, even if they did, they may not find this argument acceptable.

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* Note that while Rasmussen (1975) showed that the predicted nuclear power risks were much lower than the risks from a variety of other manmade and natural hazards, he did not make any judgment on the acceptability of nuclear power risks.

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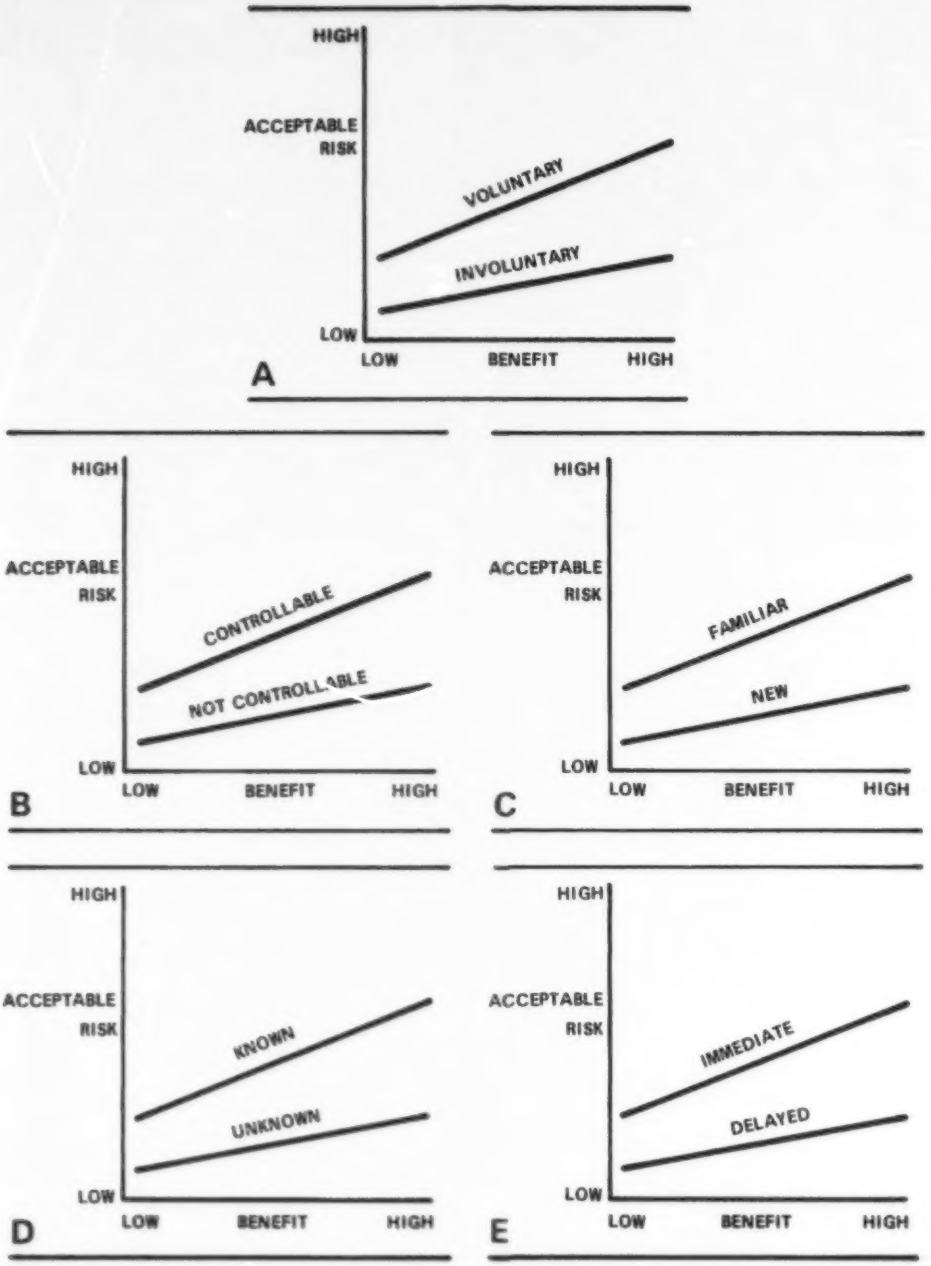

Figure F-2. Determinants of acceptable risks as indicated by revealed and expressed preferences.

Source: Slovic, P. Decision Research, Eugene, Oregon.

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The widely observed and continuing opposition to nuclear power, despite a variety of assurances from the so-called experts, suggests there are some risks that much of the public simply does not want to accept.* Although some people consider that there can be unacceptable risks, the National Academy of Engineering (1972) study on benefit-risk decisionmaking argues that _all_ risks should be viewed within an incremental benefit-risk framework. However, the material presented in this appendix does suggest that the public's perceptions of and attitudes toward different types of risk should be taken into account by societal decisionmakers when performing risk-benefit trade-offs.

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* Public attitudes toward nuclear power have been widely researched, and a number of explanations for public opposition have been put forward. For example, see Fischhoff et al. (1976), Slovic and Fischhoff (in press), Pahner (1975), Otway and Fishbein (1976, 1977), Otway (1977), Maderthaner et al. (1976), and Louis Harris and Associates, Inc. (1976).

REFERENCES

Baldewicz, W., G. Haddock, Y. Lee, Prajoto, R. Whitley, and V. Denny. _Historical Perspectives on Risk for Large-Scale Technological Systems._ UCLA-ENG-7485, School of Engineering and Applied Science, University of California, Los Angeles, California, 1974. 191 pp.

Barrager, S.M., B.R. Judd, and D.W. North. _The Economic and Social Costs of Coal and Nuclear Electric Generation; A Framework for Assessment and Illustrative Calculations for the Coal and Nuclear Fuel Cycles._ U.S. Government Printing Office, Washington, D.C., 1976. 138 pp.

Cartwright, D. "Determinants of Scientific Progress: The Case of Research on the Risky Shift." _American Psychologist_, 28(3):222-231, 1973.

Clark, R.D., III. "Group-Induced Shift Toward Risk: A Critical Appraisal." _Psychological Bulletin_, 76(4):251-270, 1971.

Ellsberg, D. _Risk, Ambiguity, and the Savage Axioms._ P-2173, The Rand Corporation, Santa Monica, California, 1961. 42 pp.

Fischer, G.W. "Experimental Applications of Multi-Attribute Utility Models." In: _Utility, Probability, and Human Decision Making_, D. Wendt and C. Vlek, eds. D. Reidel Publishing Company, Boston, Massachusetts, 1975. pp. 7-46.

Fischhoff, B. "Attribution Theory and Judgment Under Uncertainty." In: _New Directions in Attribution Research_, J.H. Harvey, W.J. Ickes and R.F. Kidd, eds. Erlbaum Associates, Hillsdale, New Jersey, 1976. pp. 421-452.

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Fischhoff, B., P. Slovic, S. Lichtenstein, S. Read, and B. Combs. *How Safe is Safe Enough? A Psychometric Study of Attitudes Towards Technological Risks and Benefits*. Report #76-1, Decision Research, Eugene, Oregon, 1976. 29+ pp. [Also published in *Policy Sciences*, 9, 1978. pp. 127-152.]

Fishburn, P.C. *Decision and Value Theory*. John Wiley and Sons, Inc., New York, New York, 1964. 469 pp.

Fishburn, P.C. *Modern Utility Theory: 1940-1970*. Technical Paper RAC-TP-160, Research Analysis Corporation, McLean, Virginia, 1965. 47 pp. [NTIS: AD625047]

Kastenberg, W.E., T.E. McKone, and D. Okrent. *On Risk Assessment in the Absence of Complete Data*. UCLA-ENG-7677, School of Engineering and Applied Science, University of California, Los Angeles, California, 1976. 54 pp.

Keeler, E., and R. Zeckhauser. *Another Type of Risk Aversion*. RM-5996-PR, The Rand Corporation, Santa Monica, California, 1969. 22 pp.

Kogan, N., and M.A. Wallach. "Risk Taking as a Function of the Situation, the Person, and the Group." In: *New Directions in Psychology: III*. Holt, Rinehart and Winston, Inc., New York, New York, 1967. pp. 111-278.

Kunreuther, H., and P. Slovic. "Economics, Psychology, and Protective Behavior." *The American Economic Review, Papers and Proceedings*, 68(2): 64-69, 1978.

Lave, L.B. "Risk, Safety, and the Role of Government." In: *Perspectives on Benefit-Risk Decision Making*, National Academy of Engineering, eds. National Academy of Engineering, Washington, D.C., 1972. pp. 96-108.

Lichtenstein, S., P. Slovic, B. Fischhoff, M. Layman, and B. Combs. *Perceived Frequency of Lethal Events*. Report #76-2, Decision Research, Eugene, Oregon, 1978. 82 pp.

Linnerooth, J. *The Evaluation of Life-Saving: A Survey*. RR-75-21, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1975. 31 pp.

Louis Harris and Associates, Inc. *A Second Survey of Public and Leadership Attitudes Toward Nuclear Power Development in the United States*. Ebasco Services Incorporated, New York, New York, 1976.

Maderthaner, R., P. Pahner, G. Guttmann, and H.J. Otway. *Perception of Technological Risks: The Effect of Confrontation*. RM-76-53, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976. 24 pp.

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(4-76)

Maurer, K.M. *A Parametric Utility Comparison of Coal and Nuclear Electricity Generation*. UCLA-ENG-7719, School of Engineering and Applied Science, University of California, Los Angeles, California, 1977. 81 pp.

National Academy of Engineering, ed. *Perspectives of Benefit-Risk Decision Making*. The National Academy of Engineering, Washington, D.C., 1972. 165 pp.

Okrent, D., ed. *Risk-Benefit Methodology and Application: Some Papers Presented at the Engineering Foundation Workshop, September 22-26, 1975, Asilomar, California*. UCLA-ENG-7598, School of Engineering and Applied Science, University of California, Los Angeles, California, 1975. 655 pp.

Okrent, D., and C. Whipple. *An Approach to Societal Risk Acceptance Criteria and Risk Management*. UCLA-ENG-7746, School of Engineering and Applied Science, University of California, Los Angeles, California, 1977. 35 pp.

Otway, H.J. *Risk Assessment and Societal Choices*. RM-75-2, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1975. 28 pp.

Otway, H.J. "The Status of Risk Assessment." A paper presented at the 10th International TNO Conference on "Risk Analysis: Industry, Governments and Society," February 24-25, 1977. Rotterdam, Netherlands. 16+ pp.

Otway, H.J., and J.J. Cohen. *Revealed Preferences: Comments on the Starr Benefit-Risk Relationships*. RM-75-5, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1975.

Otway, H.J., and M. Fishbein. *The Determinants of Attitude Formation: An Application to Nuclear Power*. RM-76-80, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976. 31 pp.

Otway, H.J., and M. Fishbein. *Public Attitudes and Decision Making*. RM-77-54, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1977. 29 pp.

Otway, H.J., and P.D. Pahner. "Risk Assessment." *Futures*, April 1976, pp. 122-134.

Pahner, P.D. "The Psychological Displacement of Anxiety: An Application to Nuclear Energy." In: *Risk-Benefit Methodology and Application: Some Papers Presented at the Engineering Foundation Workshop, September 22-26, 1975, Asilomar, California*, D. Okrent, ed. UCLA-ENG-7598, School of Engineering and Applied Science, University of California, Los Angeles, California, 1975. pp. 557-580.

Raiffa, H. *Decision Analysis: Introductory Lectures on Choices Under Uncertainty*. Addison-Wesley, Reading, Massachusetts, 1968. 332 pp.

Rasmussen, N.C. Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants. WASH-1400, U.S. Nuclear Regulatory Commission, Washington, D.C., 1975. 207 pp. [NTIS: PB248201]

Rowe, W.D. An "Anatomy" of Risk. U.S. Environmental Protection Agency, Washington, D.C., 1975. 221 pp. [An updated and extended version of this has been published as Rowe (1977)]

Rowe, W.D. An Anatomy of Risk. John Wiley and Sons, New York, New York, 1977. 502 pp.

Shinohara, Y. Fuzzy Set Concepts for Risk Assessment. WP-76-2, International Institute for Applied Systems Analysis, Laxenburg, Austria, 1976. 25 pp.

Simon, H.A. "Rational Choice and the Structure of the Environment." Psychological Review, 63(2):129-138, 1956.

Simon, H.A. "Theories of Decision-Making in Economics and Behavioral Science." The American Economic Review, 49(3):253-283, 1959.

Slovic, P. "Information Processing Situation Specificity, and the Generality of Risk-Taking Behavior." Journal of Personality and Social Psychology, 22(1):128-134, 1972a.

Slovic, P. "Psychological Study of Human Judgment: Implications for Investment Decision Making." Journal of Finance, 27(4):779-799, 1972b.

Slovic, P. "Judgment, Choice and Societal Risk Taking." In: Judgment and Decision in Public Policy Formation, K.R. Hammond, ed. Westview Press, Boulder, Colorado, 1978. pp. 98-111.

Slovic, P., and B. Fischhoff. "How Safe is Safe Enough? Determinants of Perceived and Acceptable Risk." In: The Management of Nuclear Wastes, L. Gould and C.A. Walker, eds. Yale University Press, (in press).

Slovic, P., and S. Lichtenstein. "Relative Importance of Probabilities and Payoffs in Risk Taking." Journal of Experimental Psychology Monograph, 78(3, pt. 2):1-18, 1968.

Slovic, P., B. Fischhoff, and S. Lichtenstein. "Cognitive Processes and Societal Risk Taking." In: Cognition and Social Behavior, J.S. Carroll and J.W. Payne, eds. Lawrence Erlbaum Associates, Potomac, Maryland, 1976. pp. 165-184.

Slovic, P., H. Kunreuther, and G.F. White. "Decision Processes, Rationality, and Adjustment to Natural Hazards." In: Natural Hazards: Local, National and Global, G.F. White, ed. Oxford University Press, New York, New York, 1974. pp. 187-205.

Slovic, P., B. Fischhoff, S. Lichtenstein, B. Corrigan, and B. Combs. "Preference for Insuring Against Probable Small Losses: Insurance Implications." The Journal of Risk and Insurance, 44(2):237-258, 1977.

Starr, C. "Social Benefit Versus Technological Risk: What is Our Society Willing to Pay for Safety?" Science, 165(3899):1232-1238, 1969.

Starr, C. "Benefit-Cost Studies in Sociotechnical Systems." In: Perspectives of Benefit Risk Decision Making, National Academy of Engineering, eds. National Academy of Engineering, Washington, D.C., 1972. pp. 17-42.

Starr, C. "General Philosophy of Risk-Benefit Analysis." In: Energy and the Environment: A Risk-Benefit Approach, H. Ashley, R.L. Rudman and C. Whipple, eds. Pergamon Press, New York, New York, 1976. pp. 1-30.

Starr, C., M.A. Greenfield, and D.F. Hausknecht. "A Comparison of Public Health Risks: Nuclear vs. Oil-Fired Power Plants." Nuclear News, October 1972. pp. 37-45.

Tonnessen, K.A., and J.J. Cohen. Survey of Naturally Occurring Hazardous Materials in Deep Geologic Formations: A Perspective on the Relative Hazard of Deep Burial of Nuclear Wastes. UCRL-52199, Lawrence Livermore Laboratory, University of California, Livermore, California, 1977. 15 pp.

Tversky, A., and D. Kahneman. "Judgment Under Uncertainty: Heuristics and Biases." Science, 185(4157):1124-1131, 1974.

U.S. Atomic Energy Commission. Comparative Risk-Cost-Benefit Study of Alternative Sources of Electrical Energy. WASH-1224, U.S. Government Printing Office, Washington, D.C., 1974.

U.S. Congress, Office of Technology Assessment. List of Publications, OTA-P-58, U.S. Government Printing Office, Washington, D.C., 1977. 20 pp.

Von Neumann, J., and O. Morgenstern. Theory of Games and Economic Behavior. Princeton University Press, Princeton, New Jersey, 1953. 661 pp.

Weisbecker, L.W. Snowpack, Cloud-Seeding, and the Colorado River: A Technology Assessment of Weather Modification. University of Oklahoma Press, Norman, Oklahoma, 1974. 102 pp.

Wiggins, J.H. "Balanced Risk: An Approach to Reconciling Man's Need with His Environment." In: Risk-Benefit Methodology and Application: Some Papers Presented at the Engineering Foundation Workshop, September 22-26, 1975, Asilomar, California, D. Okrent, ed. UCLA-ENG-7598, School of Engineering and Applied Science, University of California, Los Angeles, California, 1975. pp. 521-555.